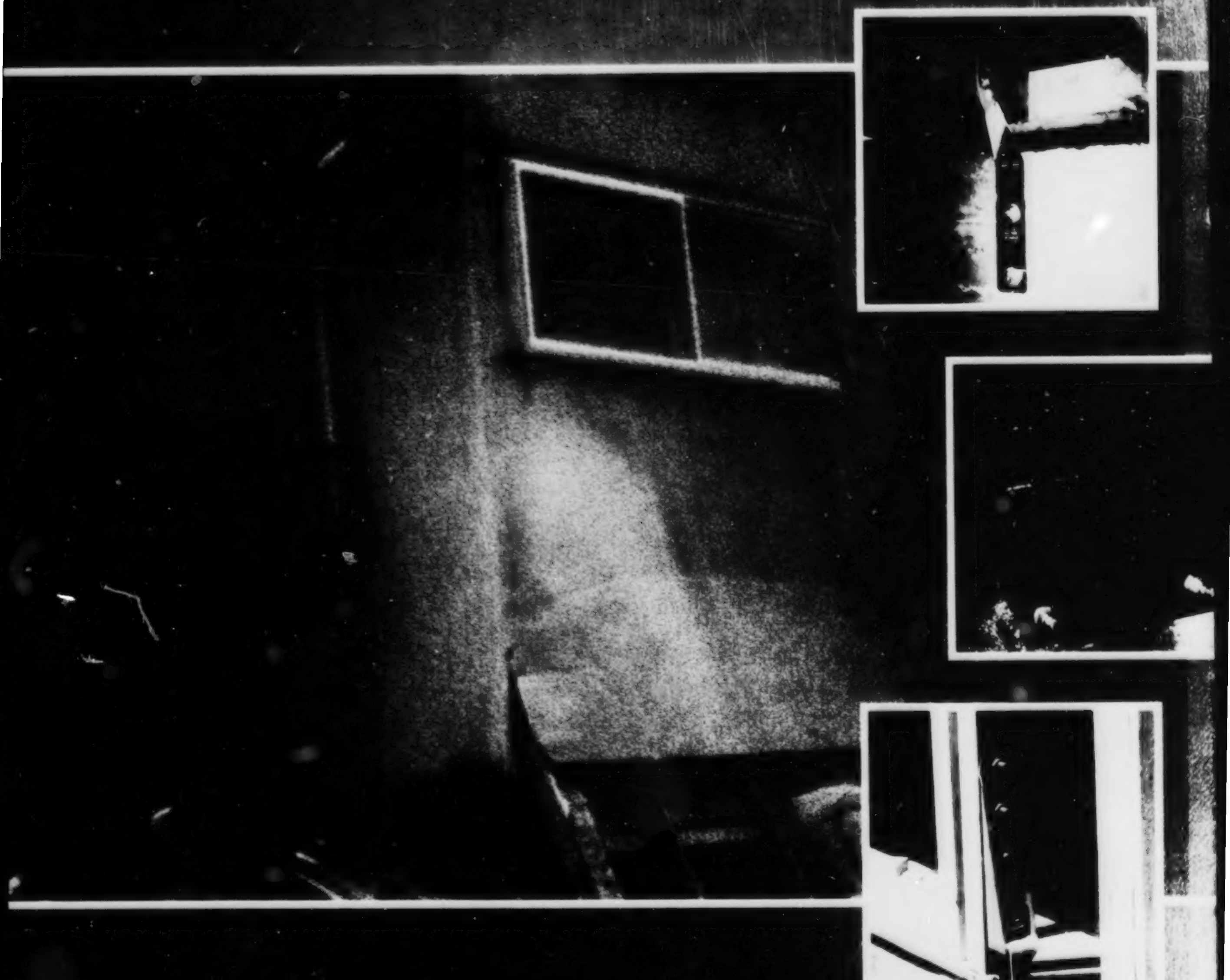
CANADA MORTGAGE AND HOUSING CORPORATION

RESIDENTIAL GUIDE TO EARTHQUAKE RESISTANCE



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1. INTRODUCTION
Destiny Favours the Prepared House

Earthquake preparedness can greatly improve a house's ability to endure an earthquake.

This chapter introduces the subject of earthquake resistance in single family houses. It introduces concepts of life safety and property preservation, outlines how an integrated approach can help in establishing priorities for upgrades, and explains how the *Guide* is organized.

Figure 1 - 1:
A House in Kobe, Japan after the 1995 Earthquake

DESTINY FAVOURS THE PREPARED HOUSE

"Before an earthquake, decisions about seismic upgrade requirements, including financing, are extraordinarily difficult. After the earthquake, every property owner wishes he or she had done more."[1]

Earthquakes strike without warning. How well your house can withstand an earthquake affects your personal safety during the quake and can determine whether you can live in the house after the earthquake.

Surprisingly, people living in areas of high seismic risks seldom appreciate the risks they face. They are not aware of the elements that determine earthquake risks and do not know the simple, relatively inexpensive corrective steps that could make their lives and property safer. The hazards from earthquakes can be reduced and earthquake-caused deaths and damage can be minimized, if actions described in this *Guide* are implemented.[2]

More than one quarter of Canada's population lives in areas that are historically and geologically prone to earthquakes of sufficient magnitude to cause widespread damage and even loss of life. Large magnitude earthquakes have occurred in both eastern and western Canada in the present century, and have damaged houses as well as other structures. There would have probably been significant loss of life if the areas affected had been populated at the levels they are today.

Figure 1 - 2:
Map Indicating Seismic Activity in Canada
(Size of circles denotes severity of earthquake.)

Table 1 - 1:
Estimates of Structural Damage Caused by an Earthquake

Type of Building	Estimated Loss %	
	Design Earthquake NBC (1985) 0.2 g peak ground acceleration	Major Subduction Earthquake 0.5 g peak ground acceleration
Single Family House Wood-Frame	2 - 5%	10 - 30%
Un-Reinforced Masonry	20 - 50%	50 - 100%
Low & Medium Rise Residential and Office	2 - 5%	20 - 30%
High Rise Residential	5 - 10%	10 - 20%

The actual force of an earthquake may be much greater than the levels currently recognized in Canada's building codes. The codes' philosophy for earthquake design is that a building should be able to resist moderate quakes without significant structural damage and major earthquakes without collapse. The objective is to reduce fatalities, to accept some structural damage, and prevent collapse. However, the codes' seismic design assumptions for houses use earthquake forces that are only 40 per cent of those that occurred in the 1995 Kobe, Japan and the 1989 Loma Prieta, California earthquakes.* The seismic provisions of current Canadian codes do not ensure that a building will be either usable or repairable after a "design earthquake"** or that its contents will not be significantly damaged.[4]

This *Guide* is intended to inform Canadians about the degree of earthquake protection offered by typical Canadian house types, focusing on existing residences. Based on earthquakes experienced in North America since the 1950s, building codes assume about five per cent of the wood-framed houses in the affected area would incur structural damage making them unusable and unrepairable. An earthquake of the magnitude that scientists predict for Canada's active seismic areas might increase that number from five per cent up to 30 per cent or greater.

The reason for the increase in estimates of severe damage is that experts now recognize that the large majority of Canadian houses are not constructed specifically to withstand the forces of an earthquake. Although most Canadian houses are built of wood, which is inherently resistant to earthquake damage, the construction does not include appropriate connecting elements.

Earthquake damage usually results from the absence of elementary construction details. House structures and contents provide limited resistance:

- because the ground they are fixed to is of poor quality,
- because foundations are not constructed to transfer earthquake forces,
- because the wood structures are not properly connected to the foundation,
- because walls are not braced to provide seismic resistance,
- because the construction methods, materials, and details used defeat the inherent resistance of the wood-frame,
- because both applied finishes and appendages (such as masonry chimneys) are not adequately secured to the wood-frames,
- and because the contents of the house are not secured using techniques that prevent them from becoming projectiles in an earthquake.

To successfully resist seismic forces, a house has to be attached to its foundation and its structural components have to be tied together. These details are essential in order to limit damage in an earthquake. However, they are often overlooked in contemporary houses and are rarely found in older ones.

* The National Building Code assigns a peak horizontal ground acceleration of 0.2 g for a zone 4 area for structural design, at Kobe the actual g = 0.8, at Loma Prieta g = 0.6.[3]

** "Design earthquake" as used in the National Building Code of Canada.

Insurance to cover the cost to replace or repair a house is another factor to consider when assessing the ability of the house to successfully survive an earthquake. Is the house insured specifically for losses caused by an earthquake? Deductibles for this coverage are rising to as much as 15 per cent of the value of the house, meaning that the first 15 per cent of the total limits of a policy would come from the home-owner's pocket. For a $100,000 home with an equal value for contents, this amounts to a $30,000 deductible on an earthquake claim. Another serious issue is the insurance industry's admitted lack of financial reserves to cover a significant earthquake in a populated area of the country.[5]

Canadians should not assume that the social safety net would lead to governmental assistance in rebuilding after an earthquake. It is noteworthy that more than one year after the earthquake in Kobe, Japan, a city similar in size to Montréal, thousands of people were still living in temporary shelters and the Japanese government advised that it cannot afford to assist private home-owners to rebuild for the foreseeable future.*

Many of the potentially damaging characteristics of existing wood-frame houses and their contents can be corrected as a renovation project, or undertaken along with other renovation projects. Canadians living in earthquake-prone areas of the country spend almost $15 billion on renovations annually.[6] If a small portion of those funds were used by home-owners to complete the most basic recommendations of this *Guide*, thousands of houses slated for renovation work this year would be much more prepared to survive an earthquake.

PURPOSE OF THIS GUIDE

Virtually all of the residents who upgraded their houses' seismic capabilities prior to the Loma Prieta earthquake in California in 1989 indicated they wished they had done more. This *Guide* has been written to increase awareness of the hazards from earthquakes and to assist those who are at risk to make good judgments regarding seismic upgrading.

This *Guide* extends the work of others in two key areas. For the first time in a widely distributed publication, the *Guide* uses an interactive checklist format to help users assess the seriousness of house deficiencies, and to determine whether they involve risk of loss of life, loss of shelter or (simply) property damage. Only by being candid about the relative risks associated with various house defects can the *Guide* help the user to be realistic in developing priorities for upgrading.

Knowing about theoretical defects and associated risks does not easily allow a reader to evaluate a particular property, nor to develop an upgrade strategy. This *Guide* assists in evaluating and establishing priorities, so that the reader can develop a strategy to balance risk, value, and practicality when planning renovations. The *Guide* also provides some construction details that are useful for both existing and new buildings.

USE OF THIS GUIDE

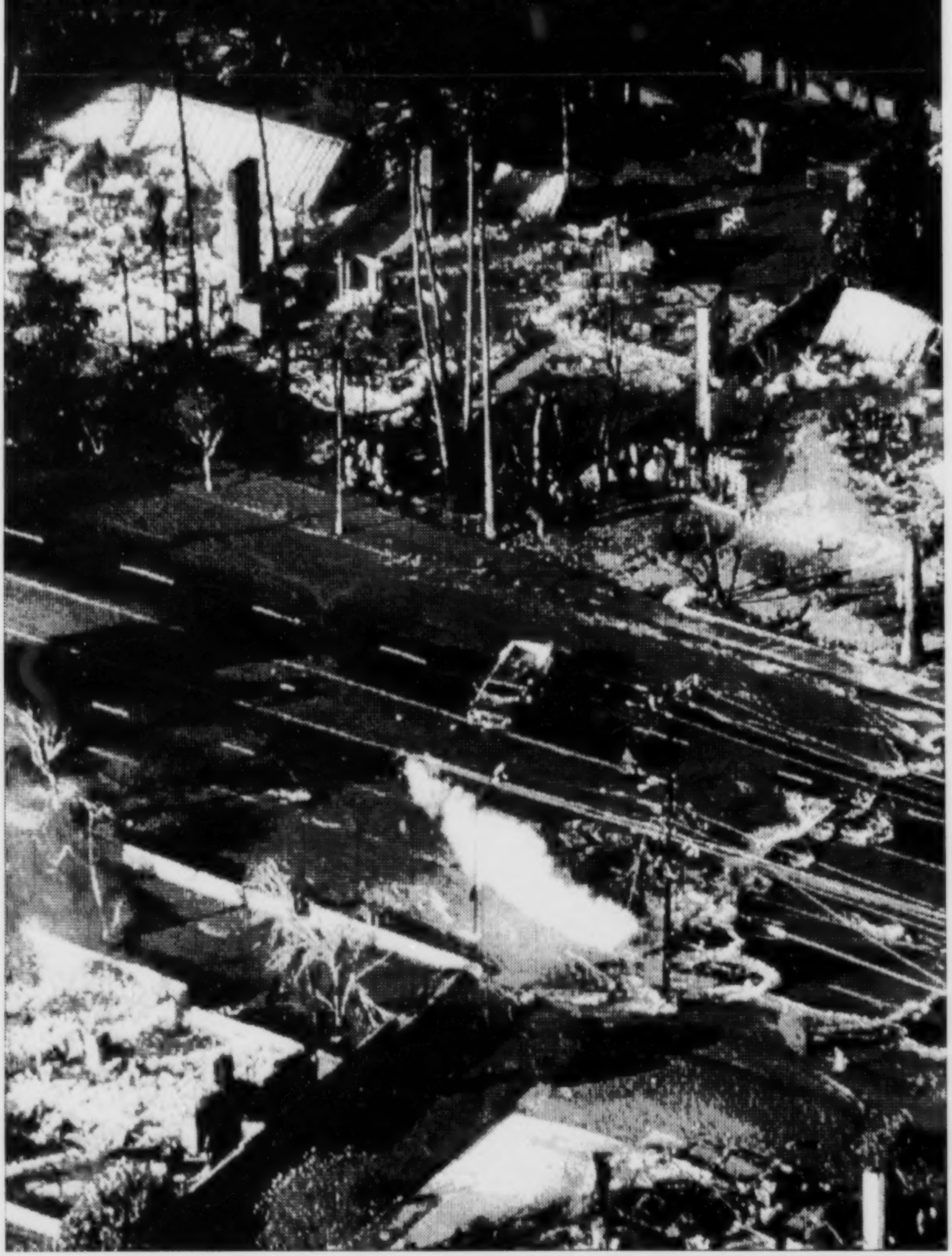
The content of this *Guide* is shaped by two underlying concerns–risk to the occupant and strength of the existing house.

Three Priorities

The seismic sections of Canadian building codes require simply that, in an earthquake, buildings should not collapse or otherwise injure or kill their occupants. They do not ensure that the post-earthquake condition of the structure or its contents will remain substantially undamaged so that the house can be safely inhabited and repaired.

* The 1995 population of Kobe City (all wards) was 1,477,000, or 3,700,000 if other affected cities in the Hyogo prefecture are included. According to the *Financial Post* market size estimates, the comparative 1994 population of the Vancouver CMA was 1,714,400, while the Montreal CMA was 3,280,400.

Figure 1 - 3:
Burned out homes of a Los Angeles street after the Northridge Quake, January 1994



This *Guide* is organized to permit the reader to assess property, houses and contents, in relation to the three following priorities:

- **First (Highest) Priority** - Maintaining personal safety during and after an earthquake;
- **Second Priority** - Retaining the house in a habitable, repairable state after an earthquake;
- **Third Priority** - Minimizing damage to the building and its contents.

It should be re-emphasized that existing codes and regulations do not address these second and third priorities, which each account for approximately one half of the property insurance claims following an earthquake.[7] Canadian houses built before 1970 were not regulated by uniform building codes or standards, meaning much of Canada's housing stock may fail on all three counts.

Integrating the Structure of the House

It is the philosophy of this *Guide* that earthquake resistant design needs an integrated approach. Too often in the design and construction of houses, a lack of awareness of structural issues leads to a completed product where "the whole is weaker than the sum of its parts." This *Guide* suggests that it is possible, incrementally, to create a house in which "the whole is stronger than the sum of its parts." The *Guide* explains how the individual elements, their connections and assemblages in a house can be successfully knit together by a comprehensive, thoughtful approach.

For Whom Is It Written?

This *Guide* is intended as a reference for builders, renovators, architects, engineers, technologists, municipal officials, and other knowledgeable parties working with existing and new single family houses. It can also be of use to the home-owner who is considering seismic upgrades to the house in the course of other renovation work.

What Does It Cover?

This *Guide* focuses on existing wood-frame houses, particularly renovations. Over time, houses are repaired, upgraded, renovated, or enlarged, all of which provide opportunities to evaluate and correct seismic deficiencies. The concepts in the *Guide* are also applicable to new construction, as are many of the construction details.

The *Guide* explains how to determine if a house needs seismic improvements and describes in simple terms how it can be done. The improvements will reward the home-owner both in terms of value through reduced damage and in the peace of mind coming from the knowledge that the inherent safety of wood-frame construction has been improved by good seismic detailing.

Where Is It Applicable?

This *Guide* may be applied in all of the high hazard earthquake areas in Canada. As these high hazard areas include two of the main populated regions of Canada, the West Coast and the Ottawa and St. Lawrence Valleys, the *Guide* has focused principally on house forms and construction techniques in these areas. However, the principles apply to any earthquake-prone area in Canada, as well as to buildings in areas prone to unusual stresses such as high winds.

When to Use It

Right now!!

It will affect your plans!!

Before embarking on repairs, upgrades, renovations, or additions to a house, read the *Guide*, use the checklists, and make earthquake resistance a key part of your plans.

Figure 1 - 4:
Typical West Coast House Damaged During the Northridge Earthquake, March 1994

How to Use the *Guide*

It is reasonably straightforward to assess the condition of a house and with that information to evaluate how that house will likely perform in an earthquake. You do not have to be an engineer to uncover and correct some of the most damage-causing details. A few weak features in the typical house tend to cause most of the damage, particularly in older houses.

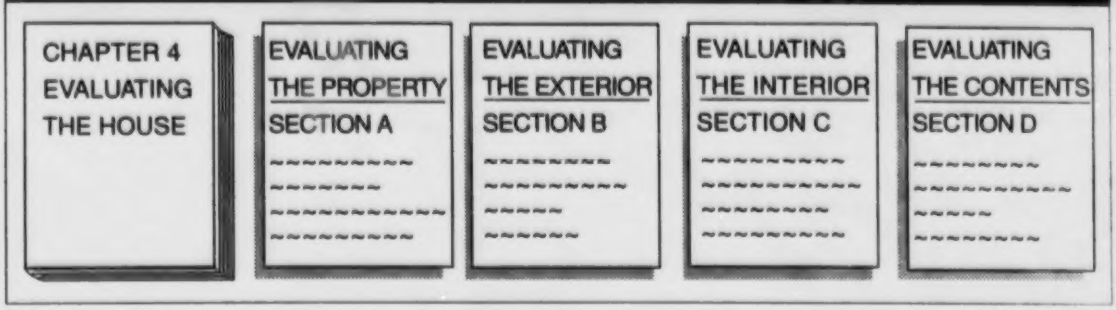
The information presented in this *Guide* flows from the general to the specific. It begins with an elementary explanation of earthquakes, outlining the geologic and man-made hazards that they trigger. It continues with a general discussion of how houses react to the forces generated by an earthquake. Next, the *Guide* provides a means of evaluating a house using a checklist system (included in Appendix H). It provides methods to help the reader make sense of the information gathered, and to develop an upgrade strategy. The *Guide* concludes with a re-evaluation of priorities and some general guiding principles about representative construction techniques that resist earthquakes.

Appropriate Use of the *Guide*

Professional building designers know that wood structures, when upgraded with metal connector systems and braced walls, out-perform non-strengthened wood structures during earthquakes.

This *Guide* includes a collection of strengthening methods that can help lessen or prevent damage to a house from earthquakes. Drawings show how various elements of the house can be made safer. These are not instructions to follow, but rather directions to guide design professionals, contractors and building officials. Details have been developed for general conditions and may not apply to specific buildings, however they do give general assistance in what to consider. It is not possible to identify every condition or potential solution that will be encountered when

Figure 1 - 5:
Organization of Chapter 4



strengthening a house, and earthquake design professionals should be relied upon when questions arise. Before starting any work, check with your local building authority for specific local building requirements.

No strategy for earthquake hazard reduction can completely eliminate risks to people or buildings, but use of known seismic engineering principles, along with common sense, can reduce the risk and make houses much more likely to survive. Understanding the construction strategies for reinforcing houses is within the ability of anyone who seeks the information. The *Guide* is written for those who want to understand the principles and to include seismic resistance details in the construction of their houses.

REMEMBER ...

Implementation of the *Guide*'s recommendations in any house will in all likelihood reduce personal injuries and property damage. Experts acknowledge that decisions about seismic upgrading and financing are extraordinarily difficult, both for owners and for public officials. The California Office of Emergency Services suggests the following principles, derived from experience:[8]

1. Never forget that you will have an earthquake.
2. Upgrades help to save lives, including possibly your own.
3. Any amount of upgrade is an advantage. The more you do the better. Even minor improvements can make the difference between repair and ruin.
4. The disruption and costs of upgrading are minor compared to the catastrophic costs of doing nothing.
5. Recovery happens sooner when there is upgrading.
6. Do NOT wait.

[1] Mr. Eadie, a Project Manager of the City of Santa Cruz Redevelopment Agency, at the time of the 1989 Loma Prieta Earthquake.

[2] Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., p. 1.

[3] Kobe 'g' taken from Earthquake Engineering Research Institute, *The Hyogo-Ken Nanbu Earthquake January 17, 1995 - AKA Kobe*, Preliminary Reconnaissance Report, EERI Publication Number 95-04, 1995, Oakland California; Loma Prieta 'g' taken from Federal Emergency Management Agency, US Fire Administration, *The Loma Prieta Earthquake Sept. 1991 Emergency Response & Stabilization Study.*

[4] Rainer, J.H., Jablonski, A.M., Law, K.T., Allen, D.E., *Earthquake Damage in the San Francisco Area and Projection to Greater Vancouver*, January 1990, NRC Client Report for CMHC - Report # CR-6026.1; private correspondence from Dr. Anne Stevens, Geophysics Division, Geological Survey of Canada, to Canada Mortgage and Housing Corporation, 11 July 1994.

[5] Voll, Jane, "We're unprepared for Canada's first catastrophic earthquake," in *Canadian Speeches: Issues of the Day*, July, 1995, p. 2-6.

[6] "Renovation Market Outlook" in *National Housing Outlook Fourth Quarter 1995, Special Supplement*, by CMHC, p. 4.

[7] Private correspondence with Prof. Robert Taylor and Prof. Carlos Ventura, University of British Columbia Faculty of Engineering, February 1996. Professors Taylor and Ventura are researching seismic damage to single family houses on behalf of a private insurance company.

[8] California Office of Emergency Services, Bay Area Regional Earthquake Preparedness Project, Fall 1992, p. 8.

2. UNDERSTANDING EARTHQUAKES
The House with Respect to Soils, Location and Seismic Hazard

Recent earthquakes in California, Alaska, Mexico City and Kobe, Japan demonstrate the obvious need to implement design and construction techniques that make houses more resistant to earthquakes. Although specifics about an individual earthquake, its strength, duration, and actual location cannot yet be predicted accurately, areas of major seismic risk are well known.

In Canada, the areas with the greatest potential for major seismic activity are also areas with large numbers of people and a great number of houses. This chapter explains the basic geological terms used to describe surface effects caused by earthquakes. It focuses on the nature of soils and the significance of locations as they impact on a house during a seismic event. The populated areas of Canada recognized as having significant potential for a major earthquake are identified.

WHAT IS AN EARTHQUAKE?

Earthquakes are a product of the constant motion of the earth's surface. The motion creates a build-up and release of energy stored in the rocks near the earth's surface. Earthquakes are the sudden, rapid shaking of the surface as this energy is released. The earth's rock surface is broken into large segments floating on a molten core. These pieces, or 'tectonic plates,' are in constant, almost imperceptible, slow motion. Much of the time the pieces are locked together at their edges, and energy begins to build up between them. When enough force accumulates, the pieces slip and the energy is suddenly released. The energy released travels through the earth in the form of waves. On the earth's surface it is experienced as ripples similar to those on a pond. Ground motions can occur in the horizontal direction (side to side) or vertical direction (up and down) or in combination. The shaking can last for a few seconds or a few minutes. After an earthquake there are frequently aftershocks, which vary from several a day to only a few per week. Aftershocks are normal; they show that the Earth's crust is adjusting after the main earthquake.[1]

WHERE EARTHQUAKES OCCUR IN CANADA

Although the Canadian population has been lucky to escape a major seismic disaster, the land has a long and continuing earthquake history. Much of Canada's population now lives in areas exposed to earthquake activity.[2]

Figure 2 - 1:
Areas of High Earthquake Hazard
(The shaded areas indicate acceleration-related seismic zones (Za) of 3 to 6)

Figure 2 - 2:
Intensity of Seismic Activity in Northern Canada
(Size of circles denotes severity of earthquake.)

Earthquake records and geological studies show that Canadian seismic activity occurs in three principal regions:

- Northern Canada — the Mackenzie Valley of the Northwest Territories, the Arctic Islands and Baffin Island,
- Western Canada — especially Vancouver Island, west of the Island and the West Coast of British Columbia
- Eastern Canada — St. Lawrence River Valley, the Ottawa Valley, New Brunswick and south of Newfoundland

Northern Region Overview

Many people are unaware that earthquakes occur in the North with as much frequency as in other parts of Canada.

However, since these areas are sparsely populated, they do not pose as great a threat in terms of amount of property damage and loss of life. It is the areas of Eastern and Western Canada that have the greatest population concentrations and where the loss of life and property could be significant; these are the areas where implementing seismic upgrading of houses will produce the greatest benefit.

Western Region Overview

British Columbia's southwest corner is the most active earthquake region in Canada. Southwest British Columbia overlies a subduction zone, where one plate slides beneath another. This subduction zone stretches from a point off the coast of northern Vancouver Island south to California. Pacific plates are separated by the much smaller Juan de Fuca Plate, a fragment of ocean floor that is sliding down under the continental margin at a rate of about 4 cm per year. The stresses built up by this subduction process have caused many recorded earthquakes in the Vancouver Island/Lower Mainland region.

Although most earthquakes are too small to be felt, an earthquake capable of structural damage can be expected to occur somewhere in the region about once every ten years. The most recent major earthquake in British Columbia happened in 1946, when a magnitude 7.3 event rocked central Vancouver Island.

In 1965, a magnitude 6.5 earthquake, centred south of the border beneath the city of Seattle, caused damage in the city and surrounding area. This event is an example of what can be expected the next time a similar magnitude earthquake occurs in an urban area of southwest British Columbia. Although no buildings collapsed, windows broke, chimneys fell and walls cracked. Bridges, roads, water and utility installations were also damaged. Seven people died as a result of the earthquake and hundreds more were injured.

Figure 2 - 3:
Intensity of Seismic Activity in Western Canada
(Size of circles denotes severity of earthquake.)

Eastern Region Overview

Eastern Canada is located in a more stable continental region of the North American Plate, and as a consequence, has a lower rate of earthquake activity than the west coast. However, large and damaging earthquakes have occurred in the East in the past, and an earthquake of Californian magnitude is expected to occur somewhere in Eastern Canada in the future.

The Ottawa and St. Lawrence river valleys are particularly susceptible. A ten-year cycle will, on average, include three events greater than magnitude 5.0, which is generally the threshold of damage. Given the age of the houses, the presence of un-reinforced masonry buildings, the more severe climate, and the absence of seismic criteria in building codes and in construction practices, a disaster, which could exceed those experienced recently in California and Japan, is inevitable.

Where to Get More Information

The seismograph network of the Geological Survey of Canada can detect all events exceeding magnitude 3 in eastern Canada and all events magnitude 2.5 or greater in densely populated areas. Detailed information can be obtained from the Web site maintained by Natural Resources Canada at www.seismo.nrcan.gc.ca.

THE EFFECTS OF EARTHQUAKES

"An earthquake unleashes a complex chain of natural events, often catastrophic, and difficult to predict. The terms given to major geologic effects of earthquakes include surface faulting, ground shaking, ground failure, and flooding from tsunamis and seiches."[3]

Surface Faulting

Faults occur when materials on opposite sides have moved relative to one another in response to the accumulation of stress. Fault movement does

Figure 2 - 4:
Intensity of Seismic Activity in Eastern Canada
(Size of circles denotes severity of earthquake.)

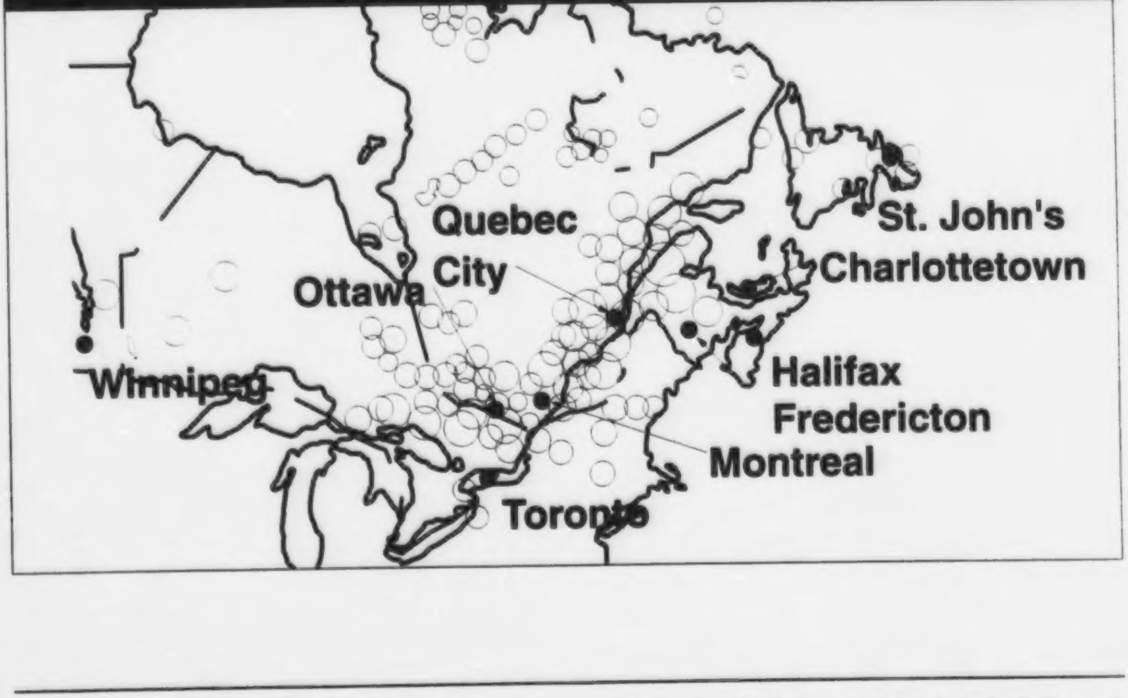
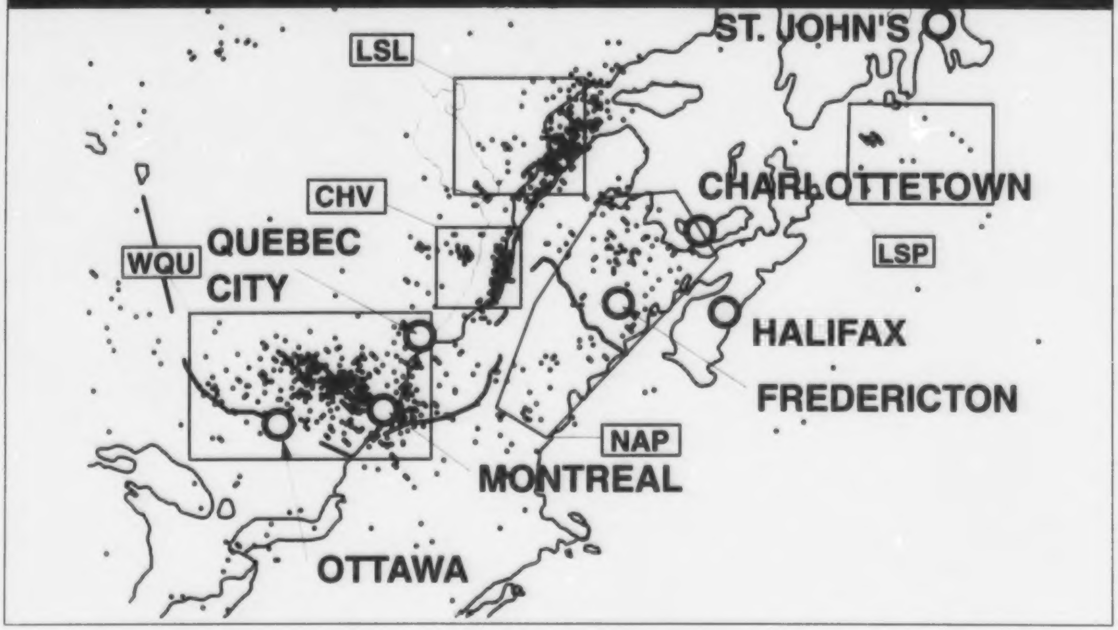


Figure 2 - 5:
Zones of More Frequent Seismic Activity in Eastern Canada



Although earthquakes can and do occur throughout most of Eastern Canada, years of instrumental recordings have identified five zones where earthquake activity is more frequent. This spatial pattern can be seen on Figure 2-5, showing earthquakes since 1985. These zones are:

WQU	West Quebec: includes the city of Montréal and extends northwest crossing the Ottawa River into eastern Ontario and Ottawa.
CHV	Charlevoix-Kamouraska: an area 100 km down river from Quebec City. This is the most seismically active and most closely monitored region in Eastern Canada.
LSL	Lower St. Lawrence: an area of diffuse activity at the mouth of the St. Lawrence River.
NAP	Northern Appalachians: includes most of New Brunswick and extends into New England. A series of significant earthquakes occurred in the Miramichi area of central New Brunswick in 1982 (the largest was of magnitude 5.7) and the area continues to record aftershocks from this series.
LSP	Laurentian Slope: an area off Canada's southeast coast, which includes the Grand Banks of Newfoundland. In 1929, a magnitude 7.2 earthquake occurred near the Grand Banks and was responsible for a large tsunami (a large ocean wave).

not always extend to the surface of the earth, but when it does, surface movement often produces a line or narrow region of visible features such as grabens (trenches), fractures, and "mole tracks" (pressure ridges). The vertical or horizontal displacement that accompanies surface faulting can destroy structures located astride the fault.[4]

Ground Shaking

Ground shaking usually causes the most widespread damage. It contributes to losses directly through vibration damage, but also indirectly by triggering secondary effects known as ground failures such as landslides and liquefaction.[5]

Figure 2 - 6:
Surface Fractures Resulting from the Loma Prieta Earthquake

Ground Failure

Ground failure is the displacement in the ground surface due to loss of strength of underlying materials. For example, ground shaking may jar loose basically unstable hillside materials causing a landslide. Another kind of landslide occurs when a soil mass moves down a mild slope with resulting cracks, fissures and differential settlements. Another very common example of failure results from the liquefaction process by which saturated silts are transformed from a solid to a liquid state. Any type of ground failure can cause severe damage to buildings.[6]

Tsunamis and Seiches

Tsunamis are large ocean waves generated by faulting or large submarine landslides on the sea floor. The waves can travel at speeds of 600 km/h (375 miles/h) and can be as high as 15 m (50 ft) or more when they reach shore.

Seiches occur within enclosed bodies of water such as lakes, reservoirs, bays, and rivers. Seiches are sloshing (periodic oscillations) of the water and can create a displacement of many metres, causing flooding and pounding damage from the wave action. Flooding can also result from dam failure or a large scale landslide into a body of water.[7]

RECOGNIZING GEOLOGICAL HAZARDS

How Soils Are Affected

Experience with earthquakes has shown that the nature of the underlying foundation soil is a major factor in the resulting damage. Different soils respond to earthquakes with varying intensities and therefore present varying degrees of risk.

Soil profiles are classified into four basic categories in descending order of seismic resistance:

1) rock;
2) stiff soil overlaying rock;
3) soil that extends to depths of 40 feet (12 m) or more of which the first 20 feet (6 m) is soft to medium stiff clay-like soil, but not more than 40 feet (12 m) of soft clay;
4) more than 40 feet (12 m) of soft clay-like material.

The profile system implies that the deeper the soft soil on which a building is located, the greater the intensity of vibration. The more a building vibrates, the greater the damage that it will sustain.[8]

In his book "Peace of Mind in Earthquake Country," Peter Yanev says the reason for the greater impact of the quake in softer soils is that the intensity of vibrations increases as the earthquake waves enter a thick layer of soft soils. These soft soils act much like jelly in a bowl, responding to and then amplifying the earthquake motions. The shock waves are transformed from rapid, small-amplitude vibrations in the bedrock into slower and more damaging large-amplitude waves. The chaotically undulating motions of these waves can be devastating at the surface,

particularly in water-saturated soils. If the foundation rests on bedrock or stiff soil, less vibration is transferred up through the foundation into the building.[9]

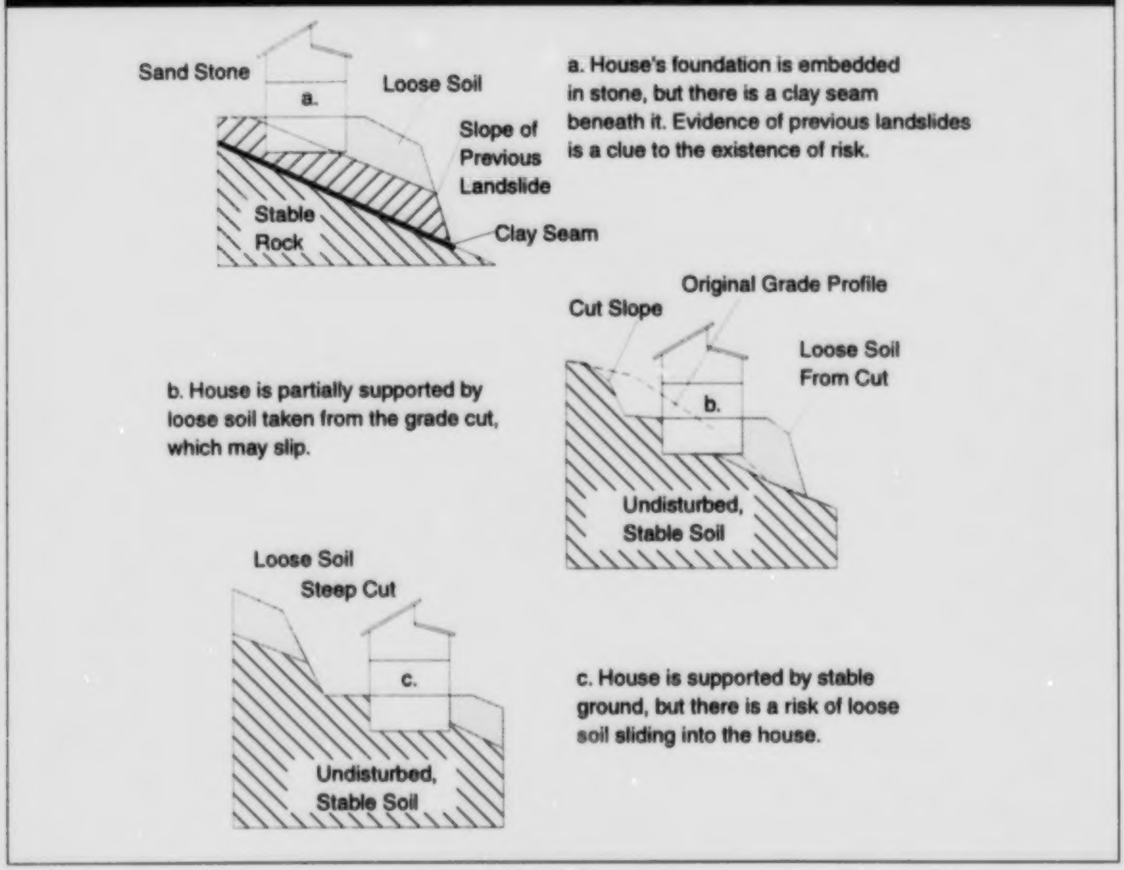
The Significance of Location

Buildings located on present and former naturally wet areas such as river deltas, marsh areas, filled or diked lands bordering a bay, or even lake beds, have a much higher earthquake risk. In "Peace of Mind in Earthquake Country," Peter Yanev explains that "soil liquefaction is a very common effect in earthquakes wherever soft soils and high water tables exist. The compaction of the soil from the earthquake vibration causes the water to flow upward and the usually sandy and muddy soils become liquefied into a kind of quicksand."[10] These locations are among the worst for construction.

Historically, the landfilling that was done to develop such wet areas creates the zones of greatest damage. This is because, when earthquake vibrations pass through soil that has a high liquid water content, the soil loses the properties of a solid and takes on those of a semi-liquid, like pudding. Foundations lose the support of the soil and settle deeper in the earth, often unevenly; this can cause houses to slump or even collapse.

Tsunamis, waves generated by earthquakes in the ocean floor, move at very high velocity, and when they approach a shoreline they can reach heights greater than 15 m (50 ft). The impact of the wave itself and the sudden rise in tidal line can devastate property along ocean water front. Seiches, which occur within enclosed bodies of water, can also create a displacement of many metres, causing flooding and pounding damage from the wave action.

Figure 2 - 7:
Landslide Potential on Natural and Altered Hillsides



Cliffs near major faults present additional risks. Because the cliffs are unsupported by ground on one side, they experience more movement during earthquakes than the level ground condition. Scientists believe that as the energy waves emerge from the ground, they are reflected and intensified by the cliff face, resulting in further amplification of the ground motions. Cliffs along the water can also be impacted by the actions of tsunamis and seiches. In general, houses along cliffs suffer significantly more damage, and therefore should be designed for the highest earthquake forces.[11]

Interestingly, like houses on cliffs, those on ridges are also exposed to a higher risk. The ridge is unsupported by ground on either side and it is believed that the energy waves are trapped within the peak of the ridge, causing the waves to be amplified in a localized area. As in the conditions near cliffs, forces on the buildings increase dramatically.[12]

Slides may occur on hillsides, ridges or cliffs. Even when the soil appears stable, it can be layered by thin clay seams—sometimes so thin as to be virtually undetectable. Seams give way when

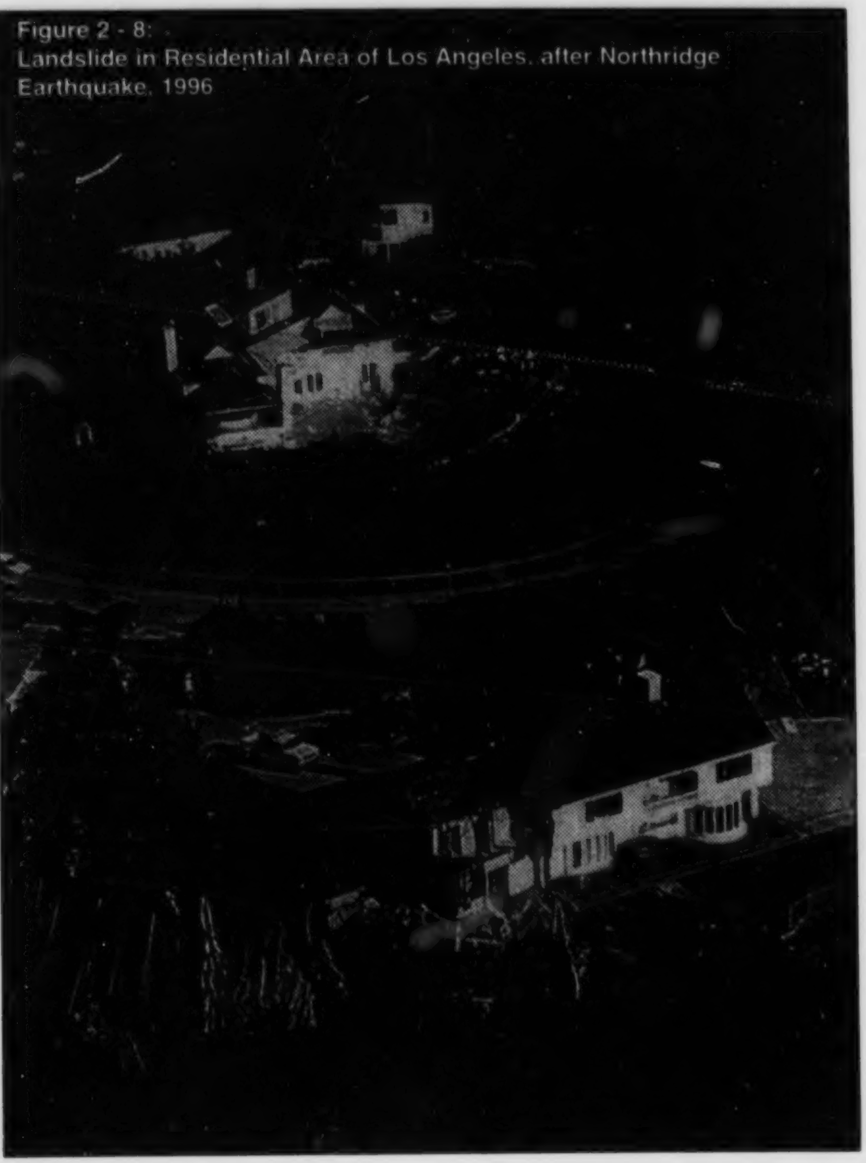


Figure 2 - 8:
Landslide in Residential Area of Los Angeles, after Northridge Earthquake, 1996

they become water-saturated or the forces of an earthquake break the very weak frictional bond holding the clay. Houses cut into the slope or built on the soil from the cut are especially susceptible. Slides cause tilting and breaking of foundations and often lead to other severe structural damage. Cut or filled slopes necessitate well-designed retaining walls, drainage systems, and properly chosen and placed fill to reduce sliding induced by earthquakes. If property is located in a known slide area, it carries an additional risk of damage.

The fundamental element for all fill sites is the material used for fill and its placement. "Typically, to properly fill a site, the material used has to have a granular or sandy component, to make it hard and less subject to shrink and swell from water saturation. Additionally, the fill has to be placed in measured layers, called lifts, and compacted to a certain percentage of its ultimate compacted state. Loosely placed fill with a high clay content does very poorly when the site is shaken by an earthquake."[20] This is the case on hillside fill sites, wet sites that have been filled, and landfill sites. If improperly engineered, all have the same response as the soft soil sites due to their low compaction.

It is obvious that the location of a house is significant in its ability to survive earthquakes. There are many geological hazards that can contribute to the damage or destruction of a house. Natural conditions include the types of soil and their geological layering, the topography of the property, the presence of water, and even the type and amount of vegetation. The seismic characteristics of a property can be improved or degraded through the knowledge and care used by those who prepared it for construction. Maintenance of the property is also an important factor in the ability of a house to resist earthquakes successfully. The seismic conditions of a location are often not obvious, but building authorities often have good knowledge of conditions. Consultation with soil engineers may also be appropriate. Unfortunately, no measures, including the application of the soundest principles of seismic engineering, can guarantee that any property can survive a quake without severe or total damage.

RECOGNIZING CONSTRUCTED HAZARDS

Houses are not only subjected to the geological effects of earthquakes, but can also be impacted because structures in the vicinity fail during the quake.

The greatest potential hazard to a community as a whole, as well as individual houses, is the failure of a reservoir. The collapse of a dam located above the community would release the force of stored water that would sweep away buildings in its path and flood the area. The failure of a reservoir would be more devastating than the effects of the quake itself. It is ironic that past seismic activity has often created the large valleys and steep canyons that are used as reservoirs. Many of the dams built to take advantage of the natural storage potential were designed before current seismic engineering theories were in practice.

On a much smaller scale, water tanks represent a similar hazard to adjacent houses. The sudden release of large quantities of water has the potential force to collapse houses or knock them off their foundations. Other damage to houses near the tank would include erosion at foundations, retaining walls and landfill, flooding of ground floor living areas, crawl spaces and basements, and damage from debris. Elevated tanks present the additional threat from the collapse of their structure on adjacent houses.

Other structures subject to earthquake damage are dikes and levees. These structures are built in naturally wet areas along rivers, adjacent to marshes, and on sandy soil bordering bays. As discussed earlier in this chapter, the water-saturated soils associated with these areas are very strongly impacted by earthquake motions. The dikes or levees, and the houses built on them, will be subjected to intense vibrations and the failure of levee structures will destroy the houses as well. Those houses located on the lands behind the dike will be impacted by a surge of water at the time of failure and damaged by flooding.[14]

Both retaining walls and swimming pools located on neighbouring sites present localized hazards. Rupturing of these structures can readily occur due to ground movements. Further discussion of these two elements can be found on p. 44.

Houses are threatened by the collapse or falling pieces of taller adjacent structures during a quake or aftershock. As previously mentioned, the water tank is an example found in the suburban environment. In the urban context, it is common for houses to be located very close to much taller apartment or office buildings. If the taller building has chimneys, parapets, sloping tile roofs, unreinforced masonry walls or veneer, the houses and occupants are endangered by the falling debris.

1 *Earthquakes - A Teacher's Package for K-6*, National Science Teachers Association, 1742 Connecticut Avenue, NW. Washington, DC 20009, October 1988, p. 11, 13

2 Data from www.seismo.nrcan.gc.ca.

3 Spangle, William E., *Pre-Earthquake Planning for Post-Earthquake Rebuilding (PEPPER)*, p. xxv.

4 Ibid., p. xxv & xxvii.

5 Ibid., p. xxvii.

6 Idem.

7 Ibid., p. vii.

8 Helfant, David Benaroya, (1989), *Earthquake Safe: A Hazard Reduction Manual for Homes*, Builders Booksource, 1817 Fourth Street, Berkeley, CA, p. 8, 9.

9 Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., p. 48.

10 Ibid., p. 53.

11 Ibid., p. 60, 62.

12 Idem.

13 Helfant, p. 9.

14 Yanev, p. 3, 75, 76, 77, 78.

3. UNDERSTANDING HOW HOUSES REACT TO EARTHQUAKES
Earthquakes Shake Up the Whole House

This chapter focuses on the individual house. It relates movement caused by an earthquake to the reactions of the house. It introduces the structural elements that are significant in seismic resistant design, as well as common deficiencies found in houses.

Figure 3 - 1:
Graffiti on this Stucco Building Underscores how Destructive Earthquake Forces Are for Unprepared Buildings

PRINCIPLES OF EARTHQUAKE RESISTANCE

A myth that must be dispelled is that all wood-frame houses are earthquake resistant. Houses are traditionally constructed to resist large vertical loads such as snow, the weight of people and furnishings, and smaller horizontal loads such as wind. Unfortunately, there are numerous examples of the destruction of both new and older wood houses in recent earthquakes on the continent. A house must be designed and constructed based on seismic resistance principles to be earthquake resistant.

The principles of earthquake-resistant design for houses have been known in North America since the 1950s but even now they are not in common practice. Resistance to their use is due to the force of traditional construction practices, the uncertainty of when, where, or even if, quakes occur, and the additional cost associated with a more thorough solution. But even a moderate increase in the attention to details can deliver wood-frame houses that are safer for their occupants and a better investment for their owners.[1]

The structural elements of any building are designed to distribute and carry the weight of the building and its vertical loads to the foundation and then into the ground. The structural system distributes some of the weight along beams and roof or floor diaphragms, but the heaviest loads are carried by walls and columns to the foundation.

Earthquake-generated motions can produce very large and chaotic horizontal and vertical forces in the structure. The sudden ground motions push and pull upon the foundations, and cause the structure to expand and compress, to bend and sway. The structure resists these abrupt movements generated from the earth through inertia, that is, the tendency of a resting object to stay still. The horizontal inertia in a building is the same that is felt when a car abruptly accelerates, while vertical inertia is comparable to the sensation felt in a rapidly rising elevator.[2]

For houses to be earthquake resistant, engineering techniques have been developed to enable a building to absorb and distribute the forces without severe damage or collapse. The objective is to provide a continuous path to successfully transfer the forces from the earth, through the foundation, to the roof structure and back. The ability of houses to respond is directly linked to their geometry, the design of the foundations, the lateral bracing of walls, floor and roof diaphragms, and the connections between all structural components.

ELEMENTS OF EARTHQUAKE RESISTANCE

Geometry of the House

The size and shape of the building, as well as the nature and location of both structural and non-structural elements, have a great influence on its performance in an earthquake.

Figure 3 - 2: Simple and Complex House Geometries

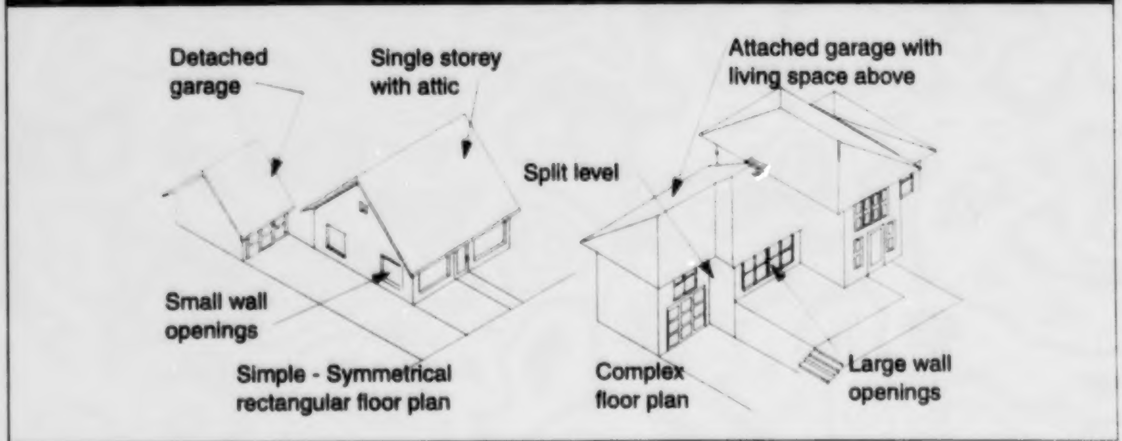
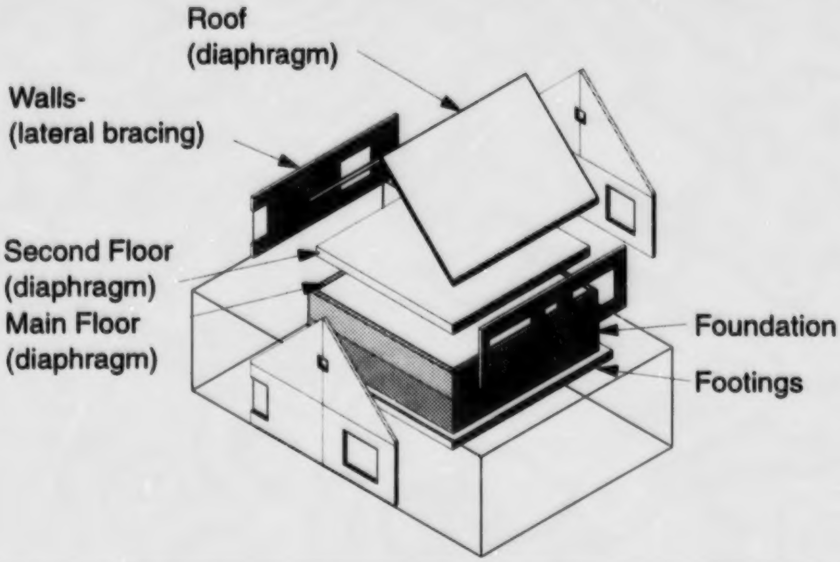


Figure 3 - 3:
Basic Structural Elements of Earthquake Resistance



Simple and symmetrical plans provide for even distribution of braced walls, and nearly continuous floor and roof diaphragms tend to resist racking successfully. This is in contrast to complex geometries with large openings in the floor and roof diaphragms or large openings in braced walls, especially at the corners of the house, which may require professional design to adequately resist seismic loads. Examples of these types of openings are large stairways or skylights, picture windows, and garage doors.

The heavier the building, and the higher the weight is above the ground, the greater the damage potential. For example, a three-storey house with a clay tile roof and masonry chimney will be much more prone to damage than a two-storey house, with wood shingles and a metal chimney.

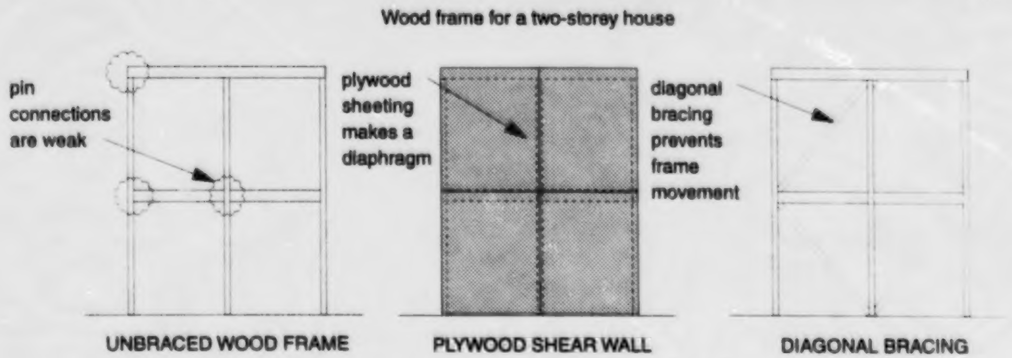
Foundations

The foundation is the first element in the house to experience the force of the earthquake and is the element that must endure the greatest forces. Quake movements are transmitted from the ground, through the foundation, and then into the wood structure of the building. The reaction of the structure and the contents of the building is then transmitted back through the foundation to the ground. The foundation ties all the building elements together so they act as a unit to resist the earthquake. The strength of the foundation, the connection of the other elements to it, and its relation to the site are all factors in its ability to resist earthquake forces. If the foundation displaces (changes position), the other support elements of the house are affected, which in turn can lead to their collapse. It is critical that the foundation survive, if the house is to survive.

Lateral Bracing of Walls

The primary function of bracing is to assist the walls and columns to resist deflection caused by the forces generated by earthquakes. Braced elements provide a more rigid and more direct path for the transfer of the forces in the house with the foundation. It is a very effective method of ensuring that the inertial loads generated by an earthquake will be resisted and carried from the individual structural elements of the frame back to the foundation and the ground.

Figure 3 - 4:
Two Methods of Lateral Bracing of Walls
(see Chapter 4, Section 4, page 108)



Lateral bracing does not contribute to the building's ability to carry normal loads; rather, it enables the vertical supports to remain stable and intact during the onslaught of motions generated by a quake. Lateral bracing also limits damage because it reduces the building's internal motion.[3]

Diaphragms, the Roof and Floors

The forces of an earthquake are usually absorbed by the floor and roof diaphragms without failures. Diaphragms support and transfer their own weight and that of the people and building contents, horizontally to the walls and other supporting elements. When failures do occur with these elements, they are generally associated with the connections where diaphragms join walls and foundations or where there are large openings or columns rather than in the diaphragms themselves.[4]

Building Materials

Because of inherent properties, some building materials perform better than others when subjected to the forces generated during an earthquake. Wood and steel are materials that have two important seismic characteristics. They are relatively light, which lessens the inertial loads that must be resisted. They are also flexible and can deflect without cracking or breaking. Materials such as concrete and concrete block can also be made earthquake resistant by following appropriate reinforcement procedures. Other masonry materials are more difficult to design to provide good seismic resistance. Although not considered structural materials, heavy claddings such as brick veneer or stucco, and finishes such as drywall, usually crack when subjected to earthquake stresses.[5]

Workmanship

Regardless of the sophistication of the seismic design and the thoroughness of the details, it is the quality of the construction that determines the performance of the house under earthquake conditions. Careless workmanship, inattention to details, and use of poor quality materials lead to weakened buildings. An elementary example is the continuing practice of constructing houses in high risk earthquake areas without any anchor bolts connecting the wood frame to the foundation. Numerous earthquake-triggered collapses or severe damage have been directly attributed to this single factor.

THE HOUSE AS A 'WHOLE'

Often the design elements that make a house dynamic and attractive also tend to make it more susceptible to earthquake damage. A simple, small, house is less likely to be influenced by seismic forces than a large, complex one. Actual damage is not a result of inherent weakness in the wood, but rather from common design or construction deficiencies:

- built on unstable ground
- weak foundation
- structure inadequately fastened to the foundation
- crawl space wall (cripple wall between the foundation and the first floor) not laterally braced
- building poorly maintained
- insufficient earthquake resistance in supporting walls
- inadequate connections between the structural elements
- slender exterior supports
- heavy roof system such as concrete tile
- too many large openings, such as large windows or garage doors
- inadequate allowance for snow or ice loads on roofs or decks.[6]

However, through attention to workmanship, seismic design and seismic details during construction, wood houses can be made very resistant to earthquake damage.

1 Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., p. 82.

2 Idem.

3 Yanev, p. 84, 86.

4 Arnold, Christopher, and Robert Reitherman, (1982) *Building Configuration and Seismic Design*, John Wiley & Sons, p. 38.

5 Yanev, p. 87.

6 Communication with Linda Brock.

Figure 3 - 5:
Photograph of Foundation without Anchor Bolts

4. EVALUATING THE HOUSE
Determining if a House can Survive an Earthquake

This chapter presents an organized method for assessing the seismic characteristics of a specific house and property. The seismic elements are grouped into four sections, each with a checklist. The checklists are included in Appendix H. An evaluation of a sample house is located in Appendix F.

PURPOSE OF EVALUATING A HOUSE

The purpose of doing an evaluation is to assess the vulnerability of the people who occupy the house, the house itself, and the contents of the house from an earthquake. The evaluation will identify specific problems, and give a good idea of how the building will perform in an earthquake. Once this assessment has been made, it can then be used to establish the priorities for seismic upgrades. Since resources are not unlimited, the evaluation will help the homeowner to make decisions on short- and long-term timing with confidence.

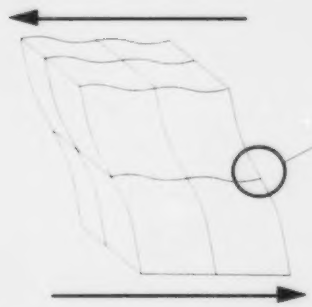
The resulting seismic upgrades that are implemented will significantly increase personal safety and reduce the damage to a house. As well, it will reduce the real and intangible costs associated with a major earthquake.

This chapter presents an organized method for evaluating the seismic characteristics of a specific house and property. In order to make the task of evaluation manageable and thorough, it has been divided into four sections, each with a corresponding checklist. The sections provide explanations of the points found in the checklists.

CHARACTERISTICS OF WOOD-FRAME HOUSES

Wood-framed houses that are carefully designed and constructed for seismic resistance, provide excellent safety during and after an earthquake. Wood structures have an inherent ability to resist seismic forces because of their light weight, their strength and flexibility. Lightness reduces the inertia that results from the structure's resistance to the earthquake-induced movement. Strength and flexibility allow the structure to deflect without breaking or becoming disconnected. The same construction, which provides successful resistance to damage during the shock of the earthquake, also provides continued ability to withstand aftershocks, which can be equally damaging.

Figure 4 - 2:
Inertia and Flexibility in Structures



The building's tendency to stay in its original location (inertia) acts as a force in the opposite direction to the ground motion

The building members attempt to reconcile the two forces (building and ground motion), along their length and their joints

The ground moves quickly under the building, in alternating directions

But just because a house is built with a wood frame does not make it "quake-proof." Wood-frame houses are likely to suffer serious earthquake damage when specific deficiencies are present. Damage is not a result of characteristics of the wood. Rather, it results from deficiencies in the building site or poor design, materials and workmanship.

USING THE CHAPTER SECTIONS AND CHECKLISTS

The process of evaluation has been divided into four categories of investigation: property, exterior, interior structure, and contents. Both the sections of this chapter and checklists have been divided into these categories. In order to make the checklists easier to use in the field, an effort has been made to refrain from overloading them with explanatory text. However, these expanded explanations are necessary, so they are provided in the sections of this chapter. The sections are divided into the same four categories, and are keyed to each checklist. The checklists themselves are included in Appendix H.

The areas covered in each of the four sections are:

Section A - Property

The first task in evaluating the impact of an earthquake on a specific house involves looking at its property and its surroundings. Knowledge of these conditions may influence the house upgrade program, as well as other important considerations such as choice of emergency exit paths, protection of services, or upgrading of structures on the property.

Section B - Exterior

After assessing the general conditions of the property, the next step in the process is a careful review of exterior elements of the house itself. Many conditions that have an impact on structural resistance and personal safety can be evaluated from the exterior.

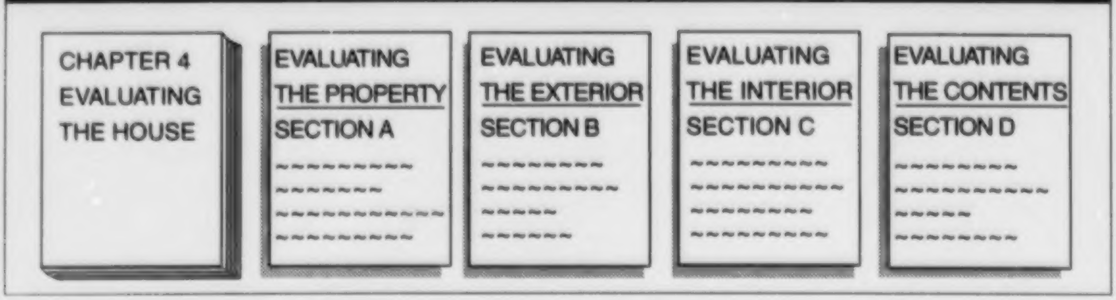
Section C - Interior Structure

After documenting the property and exterior conditions of the house, carefully examine the structure from the interior. The structural elements that contribute to the seismic resistance of the house are specifically identified. It is important that they be in good physical condition and that they be adequately inter-connected in order for the house to act as a 'whole.'

Section D - Contents

It is equally important to consider the contents of the house. Damage to the contents can make a house unusable for a long period of time; for example, consider if the plumbing were damaged. During an earthquake, the movement of the contents causes a significant proportion of earthquake-related injuries and deaths, often when structural damage is minor. Even if the building is

Figure 4 - 3:
Organization of Chapter 4



not damaged, objects in the room may become projectiles, or fall on the occupants. Contents whose seismic restraint is critical to earthquake survival include: furnishings; appliances, plumbing, mechanical, and electrical systems; and non-structural interior construction such as ceilings, light fixtures, stairways, and doors.

WORKING WITH THE CHECKLISTS

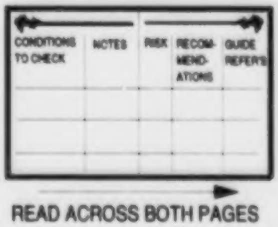
The checklists are meant to be carried with the evaluator as the assessment is made. It is a good idea to read the *Guide* and evaluation sections first. It is also a good idea to take this opportunity to take measurements of the house. Diagrams of the foundation and framing system of the house are important aids in assessing the capability of the structure to resist seismic forces, and are a starting point for the drawing of floor plans and elevations as part of the preparations for upgrading.

Notes to the Reader

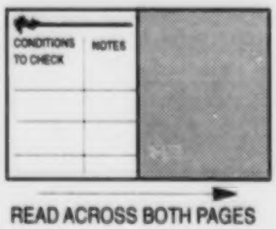
- The Checklists are included in Appendix H.
- An evaluation of a sample house is located in Appendix F.

About the Checklists

The checklists are organized across the "spread" of the *Guide* (both pages you can see are meant to be looked at together). The information on the left-hand and right-hand pages correspond to each other.



On the ***left-hand*** page are the headings **'Conditions to Check'** and **'Notes.'**

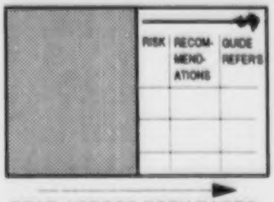


- The far-left column provides an **'Item Number'** for a particular checklist item.

- The **'Conditions to Check'** column prompts the user to check off, fill in, or otherwise acknowledge items to be reviewed.

- The **'Notes'** column provides additional information to assist in the review.

On the ***right-hand*** page are the headings **'Risk,'** **'Recommendations,'** and **'Guide References.'**



READ ACROSS BOTH PAGES

- On each right-hand page of the checklists, the three levels of **'Risk'** in ascending order of seriousness are included in the header. As the evaluation is done, one of three levels of risk is assigned to each item.

- The '**Recommendations'** column provides explanations regarding the condition under observation, to assist in understanding its significance.

- The **'Guide References'** column on the right refers to the appropriate pages in the document. A number preceded by Q (for Quake) refers to a building detail in Appendix C of the *Guide*.

It is important to be clear about the three levels of risk that are identified in this *Guide*:

"Loss of Life" is self-evident as the highest risk.

"Loss of Shelter" means that the house could be uninhabitable and unrepairable in the event of an earthquake, due to the conditions that are identified.

As used in the checklists, any lesser degree of damage is identified as ***"Loss of Property."***

The following is an excerpt from the checklist as filled out for the sample evaluation in Appendix F. The left hand page of the blank checklist looks like this:

B5.1	❑ **Canopies, Porches and Decks:** • Are canopies, porches or decks part of the exit path from the house? ❑ No ❑ Yes • Do these structures sit on reinforced concrete foundations? ❑ No ❑ Yes • Are the foundations set below grade onto undisturbed subsoil? ❑ No ❑ Yes • Is there any bracing of structural elements below the deck level? ❑ No ❑ Yes • Are wood decks finished with plywood or spaced wood members? ❑ plywood thickness: ______ ❑ wood member dimensions: ______	• These elements often collapse in earthquakes. • Raised wood decks and porches are often built without any seismic resistance. They often lack proper foundations, bracing or hold downs. • If these elements are not in an exit path, or threatening one in the event of their collapse, then upgrading may not be necessary, provided the homeowner accepts the likelihood of total collapse and loss of these elements in an earthquake. • Spaced wood members such as the 1 x 4's commonly used as nailing surfaces for shingles do not help roofs to develop adequate seismic resistance. By contrast, well nailed plywood sheathing over rafters provides an excellent bracing effect as well as improving protection from elements such as collapsing chimneys.

As filled in by the user, this entry might look like the following (added text is underlined):

B5.1	❑ **Canopies, Porches and Decks:** • Are canopies, porches or decks part of the exit path from the house? ❑ No ☑ Yes <u>Enclosed front entry porch, roof over rear french doors, deck over basement back door.</u> • Do these structures sit on reinforced concrete foundations? ☑ No ❑ Yes <u>Front entry porch is on wood on concrete blocks, rear porch is on unreinforced concrete piers set indeterminate amount into grade.</u> • Are the foundations set below grade onto undisturbed subsoil? ☑ No ❑ Yes • Is there any bracing of structural elements below the deck level? ☑ No ❑ Yes • Are wood decks finished with plywood or spaced wood members? ❑ plywood thickness: <u>n.a</u> ☑ wood member dimensions: <u>4 x 4 posts, 2 x 8 deck joists and built-up beams</u>	• These elements often collapse in earthquakes. • Raised wood decks and porches are often built without any seismic resistance. They often lack proper foundations, bracing or hold downs. • If these elements are not in an exit path, or threatening one in the event of their collapse, then upgrading may not be necessary, provided the homeowner accepts the likelihood of total collapse and loss of these elements in an earthquake. • Spaced wood members such as the 1x4's commonly used as nailing surfaces for shingles do not help roofs to develop adequate seismic resistance. By contrast, well nailed plywood sheathing over rafters provides an excellent bracing effect as well as improving protection from elements such as collapsing chimneys.

The right hand page of the blank checklist contains a column in which the user is asked to assign a risk factor for each item with the following explanation for risk assessment:

1 2 3	For each checklist item that applies to the house, assess the relative risk of the existing condition and assign a risk factor: 1 = possible loss of property; 2 = possible loss of shelter; 3 = possible loss of life.

In most cases, this right hand portion of the checklist will be annotated with the assessed risk, field notes and detailed design recommendations, as below. For the canopy/porch example above, the likely result in an earthquake will be the collapse of the rear deck and possibly the front entry porch, neither of which will cause the loss of the entire house, nor loss of life. Therefore, this condition is given a risk assessment of ***1 - Loss of Property***. As filled in, the right hand portion of this part of the checklist looks like this:

1	• If canopies, porches, or decks are part of the exit path, they must be constructed to resist an earthquake and to protect people from falling debris from above. After an earthquake, emergency egress would likely be to the front, as the rear contains tall trees, hydro poles, etc. To facilitate this, reconstruct the front porch foundation of reinforced concrete and brace the wood wall connecting the new foundation to the wood frame above.
1	• **Foundations:** Confirm that the foundations are adequate for the loads. Construct of reinforced concrete placed on bearing soil, or other engineered design. • **Connections:** Ensure the appendage structure is securely connected to the main house. Ensure that the columns are of adequate size and are securely connected to the foundation and to structure (beam/joist) above. Use engineered galvanized metal connectors. • **Bracing:** Add bracing to the open faces of the structures to provide stability. As a minimum, install X-bracing to top and bottom of each vertical post support. Refer to Item #C1, "Foundations" and Item #C8, "Structural Connections" in Checklist C for detailed information. Do all of the underlined things here re the back deck.

Master Plan Upgrade Forms

Appendix I contains "Earthquake Upgrade Master Plan" forms designed for use with the checklists. Since the checklists are comprehensive, covering many conditions that a particular house will not exhibit, the master plan sheets allow the user to summarize the upgrade elements noted in the checklists, by type (property, exterior, interior, contents) and by level of risk. Also included are columns for cost information, allowing an efficient transformation of checklist information into budget information.

For an example of the Master Plan Upgrade Forms in use, refer to the case study in Appendix F.

Section A
EVALUATING THE PROPERTY

The first task in evaluating the potential impact of an earthquake involves looking at the property and its surroundings. Knowledge of these conditions may influence the house upgrade program, as well as other important considerations such as choice of emergency exit paths, protection of services, or upgrading of site structures.

In the following pages, the "Conditions to Check" and "Recommendations" portions of Checklist A have been expanded with explanatory text and graphics, designed to assist *Guide* users in evaluating their property.

Item #

CONDITIONS TO CHECK

A1	GEOLOGY OF THE SITE AND THE AREA
	The geology of the site and the surrounding area establishes the basic conditions that affect the resistance of houses to earthquakes.
A1.1	❑ **Known Faults:** The presence of a fault near a house is more likely to increase the forces acting on that house in an earthquake. Historically, faults are often not discovered until a major earthquake occurs. However, many faults have been mapped in Canada and this information is available from Natural Resources Canada, which will also perform a site specific hazard calculation.
A1.2	❑ **Hills, Cliffs and Ridges:** Earthquakes cause slides to occur on hillsides. Houses cut into the slope are especially susceptible. Slides cause tilting and breaking of foundations and often lead to other severe structural damages. Cliffs near major faults present additional risks. Because the cliffs are unsupported by ground on one side, they experience more movement during earthquakes than those experienced on a level ground condition. Cliffs along the water can also be impacted by the actions of tsunamis and seiches. Houses on ridges, like those on cliffs, are also exposed to a higher risk. The ridge is unsupported by ground on either side and therefore experiences more movement during quakes than what is experienced on level ground. As in the conditions near cliffs, forces on the buildings increase dramatically.
A1.3	❑ **Wet Areas:** Buildings located on present and former naturally wet areas such as river deltas, marsh areas, filled or diked lands bordering a bay, or even lake beds have a much higher earthquake risk. Water-saturated soil presents particular hazards in areas prone to earthquakes. When soil becomes saturated with water, it exerts greater pressure on foundations, foundation walls, and retaining walls. Coupled with gravity, water-saturated soil on a slope exerts far more pressure on anything in its path during an earthquake. The combination of slope and the saturated soil creates a greater potential for sliding.[1]

RECOMMENDATIONS

- See Chapter 2, page 17, a general discussion of geological conditions affecting building sites.
- Houses near the specific geological conditions noted should be designed to withstand the highest expected earthquake forces.
- Seek expert advice when considering property with the following known or suspected types of conditions.

❑ **Known Faults:**

- If a house is located on or near a known fault line, then it should be strengthened and protected according to the full measure of recommendations in the *Guide*.

❑ **Hills, Cliffs and Ridges:**

- Cut or filled slopes necessitate well-designed retaining walls and drainage systems. Fill materials must be specifically chosen and placed to reduce sliding induced by earthquakes.
- Property located in a known slide area carries an additional risk of damage and should be evaluated by a geotechnical consultant.
- Generally, property located on or affected by hills, cliffs and ridges should be strengthened and protected according to the full measure of recommendations in the *Guide*.

❑ **Wet Areas:**

- Seek expert advice on upgrading when faced with these kinds of conditions.
- Check municipal engineering and building departments for further information regarding the geological conditions of your area.
- Generally, use any repair or renovation project that involves excavation as an opportunity to check the condition of site drainage and improve it where necessary.

Item #	CONDITIONS TO CHECK

A1.4

❑ **Soils:**
Investigation of recent major earthquakes by scientists has shown that the type of soils under structures is a major factor in the damage they sustain. Different soils respond to earthquakes with varying intensities and therefore present varying degrees of risk.

Soil profiles are classified into four basic categories in descending order of seismic resistance. The classification indicates that the deeper the soft soil on which a building is located, the greater the intensity of vibration. The more a building vibrates, the greater the damage that it will sustain.[2] The categories are:

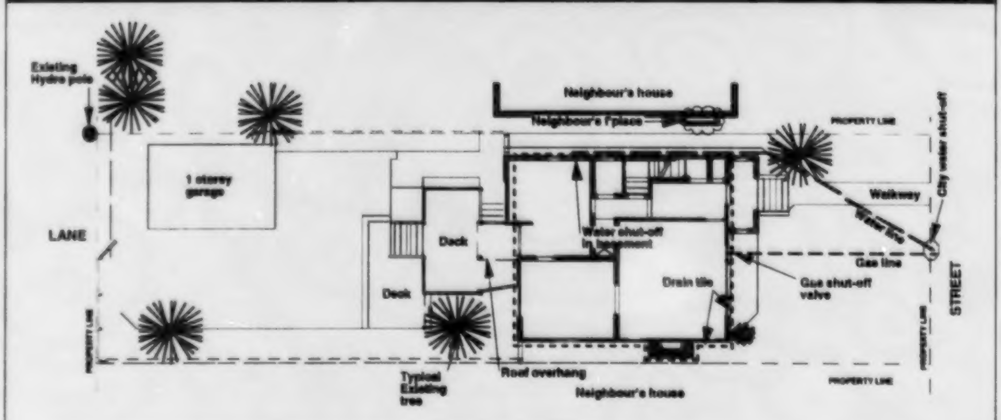
1) Rock
2) Stiff soil overlaying rock
3) Soil that extends to depths of 12 m or more of which the first 6 m is soft to medium stiff clay-like soil, but not more than 12 m of soft clay
4) More than 12 m of soft clay-like material

Those at the top of the list are generally better from a seismic standpoint. Rock and stiff soils overlying rock generally transmit less earthquake forces to a house. Deep soils, clay-like soils, landfills, soils in alluvial plains, and uncompacted saturated soils are subject to excessive vibration and liquefaction in an earthquake.

A2 **SITE FEATURES**

Elements on and off the site that might be a hazard.

Figure 4A - 1:
Typical Site Plan Illustrating Site Features



RECOMMENDATIONS

❑ **Soils:**

- Check municipal engineering and building departments for further information regarding the geological conditions of your area.
- Where Class 3) and 4) soils are encountered, use expert design advice to resist seismic reactions imposed by these soil conditions.
- The fundamental element for all fill sites is the material used for fill and its placement. The material used has to have a granular component and it has to be placed in measured layers with controlled compaction. This is the case on hillside fill sites, filling of wet sites, and landfill sites. If improperly engineered, all have the same poor structural characteristics under seismic conditions.

Sketch the house, its property and surroundings in order to diagram conditions and hazards. Include:

- Tall trees
- Swimming pools
- Utility poles
- Accessory structures
- Retaining walls and free standing walls
- Locations of utilities
- Foundation drainage
- Neighbours' hazards

Appendix F includes a more complete site plan as a case study.

Item #	CONDITIONS TO CHECK
A2.1	❑ **Tall Trees:** Depending on their age, size, and health, tall trees present potential hazards, both under seismic and storm conditions. The hazard should be weighted against the positive factors they provide of summer shade, beauty, air quality and habitat for birds and animals.
A2.2	❑ **Swimming Pools:** Damage to swimming pools is usually related to their proximity to the origin of the earthquake or a fault line. Ground movement generated by earthquakes can readily cause rupturing of pool tanks. Along with physical damage to the pool tanks, earthquakes can also cause damage from water escaping, either from a rupture or from sloshing. Hillside pools should take into consideration what is located downhill that would be affected by the sudden release of water and accumulated debris due to either sloshing or rupture.
A2.3	❑ **Utility Poles:** While some modern utility pole design and installation standards consider earthquakes, there is a tendency as a pole "ages in place" for it to become a support for loads never anticipated. A good example of this is the addition of heavy cable television wires to poles never designed to support them. Wooden poles are usually heavily treated with preservatives to lengthen their service life, however these gradually leach out. Older poles often exhibit surface decay and may also be decayed to their core.
A2.4	❑ **Accessory Buildings:** Many houses are attended by free-standing accessory buildings such as garages and gardening structures. They range widely in age and quality and must be evaluated accordingly. Outbuildings are often badly founded, that is, sitting on small posts or piers, without reinforcement and poorly fastened down. Such structures may not be worth upgrading. Conversely, a recent vintage garage may sit on a reinforced concrete foundation with some anchor bolt connections. It may be finished with exposed studs inside, allowing easy bracing. And its relatively short spans may mean the supporting roof structure is over-designed, hence more earthquake resistant. To further confuse the issue, the same new garage may be weakened by its large opening for automobile access. If an accessory structure is potentially usable as a post-earthquake shelter, this may be a useful first step to safety in a situation where the principal house is likely to be rendered uninhabitable after an earthquake, but budgets do not immediately permit its upgrade.
A2.5	❑ **Retaining Walls and Free Standing Walls:** Even though they are designed to contain the earth, these structures may easily collapse due to ground movements. Retaining walls are unevenly loaded by design and therefore present a collapse hazard in an earthquake, especially if the soils being retained are very wet and poorly drained. Free-standing walls such as those that often define property boundaries are seldom constructed to withstand earthquakes. If constructed of heavy materials such as brick, stone or concrete, they may be hazardous as they collapse. When retaining walls are constructed to stabilize a slope, their failure may allow the hillside above to slide into a house. Where they are used to retain fill on a sloping site, a failure of the wall could jeopardize the house by allowing the soil to slip away from under the house. The collapse of the wall and the movement of the soil behind it could also threaten structures below.

RECOMMENDATIONS

❑ **Tall Trees:**

- Check the root system of trees close to the house. Shallow rooted species such as alders are more prone to toppling in an earthquake. Some trees do well in groves, but are weak as individual specimens.

- If the large trees are retained, their potential hazard can be reduced by care and maintenance. For example, about every 5 years, an arborist should remove any dead or diseased limbs, and do a general pruning. The arborist will be able to maximize the life of specimen trees and also advise when they have become a significant collapse hazard, at which point they should be removed.

❑ **Swimming Pools:**

- There is little that can be done to protect pools from local ground disturbances, except to site the pool on geologically stable soil. New pools should be positioned on solid soils or be thoroughly designed to resist seismic movements.

- Maintenance of the pool structure, and any retaining walls associated with the pool, will reduce the risks of tank rupture.

❑ **Utility Poles:**

- Examine any utility poles whose collapse might damage the house or expose it to electrical hazards. Look for signs of surface decay or apparent overloading, also poles that are leaning. Where doubtful conditions are discovered, lobby the utility for repair or replacement, meanwhile plan emergency paths of egress away from pole hazards.

- Support street and lane upgrading measures that include undergrounding of electrical utilities.

❑ **Accessory Buildings:**

- Evaluate accessory structures in the same fashion as you would a house, using the *Guide*.

- If the accessory structure is significantly less earthquake resistant than the house, either upgrade it or, if the decision is taken that it will be allowed to collapse, then plan emergency egress routes to avoid it and do not use it as a storage location for emergency supplies.

- If the accessory building is as strong or stronger than the house, consider using it as an emergency post-earthquake shelter. It will likely cost less to make the smaller structure more earthquake resistant than the house.

- As many accessory structures are located closer to utilities, consider the smaller structure's usefulness as an emergency shelter in the context of a possible utility pole collapse.

❑ **Retaining Walls and Free Standing Walls:**

- For structures to remain intact, reinforcement similar to that used in the construction of concrete and masonry buildings is necessary. These walls must have substantial footings, horizontal and vertical steel reinforcing in both the footing and the wall, and if constructed of masonry, should be fully grouted and reinforced.

- Because both retaining and freestanding walls are exposed to rain and snow, they should be protected with a weather cap. Retaining walls should be further protected below the finished grade from saturated soils using a membrane-type waterproofing. Without protection, water seepage into the wall will seriously degrade both concrete and reinforcing.

- Water saturated soil behind retaining walls exerts additional pressure, which increases the forces acting on the walls when impacted by earthquakes. Provide a foundation drainage system behind walls, and create a trough above, to control the water.

- Further information is given in Chapter 4, Section A, page 49.

- Appendix C of the *Guide* provides technical details for upgrading retaining walls and free standing walls.

Item #	CONDITIONS TO CHECK
A2.6	❑ **Underground Utilities:** During an earthquake, both the ground and the house are going to move. Because most underground services are rigid, they could be torn from their connection points. Utilities may produce the following hazards: GAS — explosion, fire WATER — erosion, water damage STEAM — rupture, scalding SEWER — erosion, water damage, health hazard STORM WATER — water damage, health hazard ELECTRICAL — electrocution, fire Fire following an earthquake is a very real possibility, especially when failures occur in the structure of the house. The gas service is the most common fire source. A pipe is often severed in the foundation area or in an area where the structural framing has collapsed. Movement of gas fired appliances during the seismic event can also break gas lines.

RECOMMENDATIONS

❑ **Underground Utilities:**

- If severe ground settlements or slides occur in the vicinity of your property, underground services such as gas, water, steam, sewer, storm water, and possibly phone and electrical power are very likely to be damaged. You will recognize there is a problem because the services will not be available at the house.

- In this circumstance the action to take is:
  (1) Try to notify the utility company;
  (2) Protect yourself and your valuables from the hazard;
  (3) Provide warning signs in the vicinity of likely hazards such as an open gas line or exposed power lines.

- **Gas:**
  It is important to know the location of your gas meter and its exterior shut-off valve. Provide a wrench of the correct size near the valve in case it needs to be closed because of a suspected gas leak. Or, consider installing an automatic valve that shuts off gas to the house if an earthquake occurs. Remember that only a qualified gas fitter should re-open the valve and check piping and re-light the gas appliances.

- **Propane:**
  Recommendations are the same as for gas, plus the addition of seismic restraints to surface-mounted tanks.
  Many propane tanks use small diameter, semi-rigid pipe to connect the gas from the tank to the house. These should be carefully inspected for leaks after an earthquake.

- **Water:**
  Know the location of your water shut-off valves; there are often two. One is located between the house and the city water line, usually in front of the house near the property line. The other is often located inside the house where the incoming water first enters. Store the tools needed to close the valves in a convenient location near the inside valve. Or, consider installing an automatic valve that will shut off water to the house if an earthquake occurs.

  Maintain an emergency supply of drinking water. Unless treated, however, water has a shelf life of about six months, meaning it must be discarded and replenished twice yearly. Tablets are available that will extend the shelf life of the water.

  There are several ways to maintain an emergency water supply. One good method is to keep some frozen in a freezer. Another is to place one or more well-sealed barrels of water free standing in the rear yard, away from collapse hazards. In a post-earthquake situation, the barrel can be moved to wherever temporary shelter is available.

- **Fire Protection:**
  In addition to fire extinguishers in the house, install extra units in the accessory buildings and vehicles. When needed in an emergency, they will be more accessible in some locations than others.

Item #	CONDITIONS TO CHECK
A2.7	❑ **Foundation Drainage:** Drainage systems for foundations, foundation walls of the house, and retaining walls on the property are very important if the structures are to successfully resist earthquakes. Water-saturated soil presents an additional hazard. When soils become saturated, they exert greater pressure on these supporting structures. Water-saturated soil exerts far more pressure on anything in its way when hit by an earthquake. On a sloped site, the pressure of the saturated soils, coupled with gravity, presents an even greater potential for sliding.

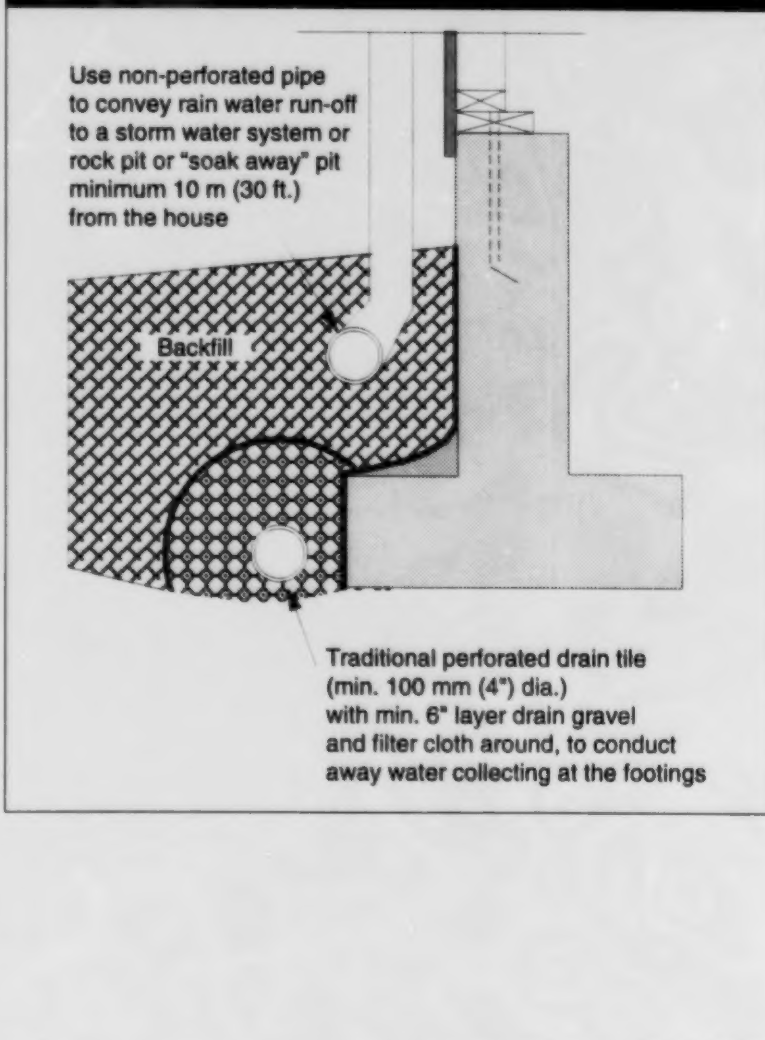
RECOMMENDATIONS

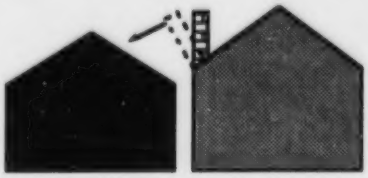
❑ **Foundation Drainage**

- Make a diagram of the drainage system for the house and retaining walls with specific attention to determine whether the following desired conditions exist:
  - The contours of the land encourage storm run-off to move away from the foundation.
  - Downspouts do not dump water near the foundation.
  - Downspouts drainage system is independent of that for the footings.
  - The retaining walls have drainage systems.
  - Water drainage for the site is independent of the footing drainage system around the house.

- Footing drains should be run separately from all other site drainage. Combining the two systems increases the chance of damaged or clogged lines, which would allow the adjacent soils to become saturated. Unfortunately, this is often not possible in older homes without a major reconstruction of the foundation drainage.

Figure 4A - 2:
An Excellent Drainage Alternative Embodying the Above Design Principles



Item #	CONDITIONS TO CHECK
A2.8	❑ **Neighbours' Hazards:** Consideration must be given to the effect the elements on adjacent properties may have when evaluating the impact of an earthquake. For example, do the neighbouring houses have chimneys or other elements facing your property that might fail? Is a neighbouring building substantially taller or very close? Do these and other conditions constitute a hazard to your safety? 

[1] Helfant, David Benaroya (1989), *Earthquake Safe: A Hazard Reduction Manual for Homes,* Builders Booksource, 1817 Fourth Street, Berkeley, CA, p. 12.

[2] Ibid., p. 8, 9.

RECOMMENDATIONS

❑ **Neighbours' Hazards:**

- Evaluate the hazards on neighbours' properties using the checklists and these notes. Try to develop a co-operative upgrade approach with neighbours where hazards exist.
- Where this is not possible, avoid planning emergency egress paths in proximity to neighbours' risks. Add upgrade strategies such as general wall strengthening in those areas where collapse potential from a neighbour exists. Refer also to Chapter 4, Section C, pages 106 to 113.

Section B
EVALUATING THE EXTERIOR

After assessing the general condition of the elements on the property, the next step in the analysis process is a careful review of the exterior of the house itself. Many conditions that have an impact on its structural resistance, as well as those that affect personal safety, can be evaluated from the exterior.

Item #	CONDITIONS TO CHECK
B1	**CONDITIONS AND CONSTRUCTION OF THE EXTERIOR**
	The general condition of a house is a good indicator of its seismic worthiness. By carefully evaluating the exterior of the house, elements of the house that will cause problems in the event of an earthquake can be identified. Their condition has a direct bearing on the structure's ability to withstand the forces of an earthquake.
B1.1	❑ **General Condition of Exterior:** A house in poor condition often has structural as well as cosmetic problems. Where water in the form of snow or rain has entered a building, the structure will degrade over time. Depending on when the house was constructed, the placement and size of doors and windows, the type of wood structural frame, and particularly the type of sheathing and cladding, will vary. All are factors in the seismic characteristics of the house.
B1.2	❑ **Grade Conditions:** Where wood has been in contact with the ground, it will be attacked by mold and mildew, insects such as carpenter ants and termites, and possibly wood rot, all of which decrease the capabilities of the structure to resist earthquakes. The connection of the wood frame of the house to the foundation and earth is a zone that must resist very large seismic forces and is one where structural failures frequently occur. The contours of the land adjacent to the house should slope away to encourage snow and rain water run-off to move away from the foundation. Water-saturated soils present a hazard because they exert greater pressure on the structure supporting the house. On a sloped site, the pressure of the saturated soils, coupled with gravity, presents an even greater potential for sliding. Water against the foundation can lead to the degradation of the foundation, and in the case of basements, can lead to the inconvenience of water in the basement.
B1.3	❑ **Construction of the Exterior:** Depending on when the house was constructed, the placement and size of doors and windows, the type of wood structural frame, and particularly the type of sheathing and cladding, will vary. All are factors in the seismic characteristics of the house.

RECOMMENDATIONS

Check municipal engineering and building departments for information regarding the age of the house, building techniques, materials used, as well as the geological conditions of your area that are recognized as having maintenance or seismic implications. Other sources of information are the local archives, land titles office, and local house builders' association.

❑ **General Condition of Exterior:**
Inspect the house from the roof peaks down to the ground, and below in basements and crawl spaces, at least annually. Look for areas where water might be entering the house, such as:

- Flashing around chimneys, windows, and changes in the plane of the roof;
- Cracks in masonry or stucco walls; or splits and knots in wood cladding;
- Wood trim, which needs regular maintenance such as painting and caulking.

- Investigate the construction of the exterior walls. It is often possible to examine the "skin" of the house, as well as its structure, in unfinished rooms, crawl spaces, or attics. Another opportunity is through openings cut for things like dryer vents and bathroom fans. It is also important to determine how the materials are connected, such as the nail size and frequency for sheathing and siding, as well as for the interior wall finishes such as drywall. Both the characteristics of the materials and the methods of connecting determine the resistance of the element to seismic forces.

❑ **Grade Conditions:**

- Where wood has been in proximity of the ground, check for decay or insect damage: repair if materials are degraded.
- Provide a minimum of 200 mm (8") separation between wood and earth.
- Contour the land to encourage snow and rain water run-off to move away from the foundation.
- Where grade conditions do not permit the ground to be sloped away from a house for a considerable distance, such as in narrow side yards between houses, create a trough so that groundwater runs as far away from the walls as possible. Even 300 mm (12") of drainage away from a foundation wall is beneficial.
- Locate the discharge of downspouts so they do not dump water near the foundation.
- Run site and roof drainage in a piped system that is independent from the foundation/ footing drainage system for the house.

❑ **Construction of the Exterior:**
Investigate the construction of the exterior walls. It is often possible to examine the "skin" of the house, as well as its structure, in unfinished rooms, crawl spaces, or attics. Another opportunity is through openings cut for things like dryer vents and bathroom fans. Try to determine the location and extent of braced walls (for an explanation of braced walls, see Chapter 4, Section C, page 108). It is also important to determine how the materials are connected. Look for things such as the nail size and frequency for sheathing and siding as well as for the interior wall finishes such as drywall. Both the characteristics of the materials, and the methods of connecting, determine the resistance of the element to seismic forces.

Keep the exterior in good repair to reduce structural degradation.

Item #

CONDITIONS TO CHECK

	• **Older Exterior Construction:** Houses built prior to about 1940 usually have horizontal or diagonal board sheathing under their exterior finishes, which has some seismic value, although less than plywood. In the west, materials such as stucco were often applied over horizontal and vertical wood lath, creating a drainage cavity in the walls that reduces long-term wear as compared to many more modern stucco applications. Houses built between about 1940 and 1975 may have fiberboard as the sheathing material, which is inferior to both boards and plywood as a seismic material. Houses finished in stucco on the exterior built prior to 1970 will often have the stucco applied over horizontal and vertical wood lath, creating a drainage cavity in the walls which reduces long term wear as compared to many more modern stucco applications. The metal lath usually used today may produce a more seismically tolerant finish where the quality of the application is sufficient to keep out moisture. Houses built after about 1975 are more likely to have plywood or oriented strand board (OSB) sheathing, which is superior to most other sheathing materials for seismic performance. • **Recent Exterior Construction:** In the 90s, some houses are being built using rigid insulation on the exterior of the wood frame with diagonal metal braces installed for seismic resistance.
B2	**CONVENTIONAL HOUSE TYPES**
	Configuration and the number of storeys affect the seismic characteristics. While most every house in Canada is slightly different from its neighbours, there are actually only a few generic house types that describe most of the Canadian housing stock, from an earthquake standpoint. These classifications are based on configuration and the number of storeys.

RECOMMENDATIONS

- **Older Exterior Construction:**
  Wherever exterior walls are exposed during renovations or repairs, examine the materials, especially the sheathing materials. Where the structure of the walls is exposed, either the interior studs, or exterior studs or sheathing, use the opportunity to add bracing.

  If cripple wall construction exists at the base of the house, upgrade the cripple wall's lateral capacity by adding seismic bracing and steel connectors.

  For applicable details, see Chapter 4, Section C, page 102.

- **Recent Exterior Construction:**
  For newer homes, contact municipal officials and the builder to determine the exterior construction.

  But commonly, the exterior walls have 1" x 10" boards, reused from the forms for the concrete foundation, applied horizontally as the sheathing on the lower walls. When the surplus forming boards are used, usually at the second story, the reaming upper walls are sheathed with oriented strandboard (OSB) or plywood.

  If builders wish to reuse forming boards, these should be applied only to the upper walls of the house, never to the cripple wall or main floor. For good seismic performance of the house and the best use of materials, plywood should be installed (and correctly nailed) at the lower walls.

Simple and symmetrical plans provide for even distribution of braced walls, and nearly continuous floor and roof diaphragms tend to resist racking successfully. This is in contrast to complex geometries with large openings in the floor and roof diaphragms or large openings in braced walls, especially at the corners of the house, which may require professional design to adequately resist seismic loads.

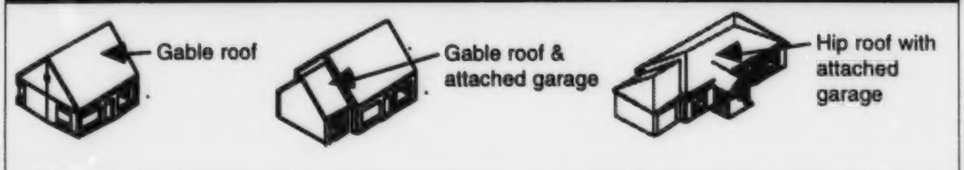
Item #

CONDITIONS TO CHECK

- **The Bungalow:**
  Because the bungalow is the most cost-effective form of housing in most parts of Canada, it is an extremely common house type. It is characterized by the living space being on a single storey. It is constructed with a variety of roof configurations. This house type may be built on a concrete slab, over a crawl space or have a partial or full basement, but is designed so that the main floor is close to the adjacent ground level.

  The bungalow may be built with an attached or detached garage, the latter sometimes connected to the house via a "breezeway."

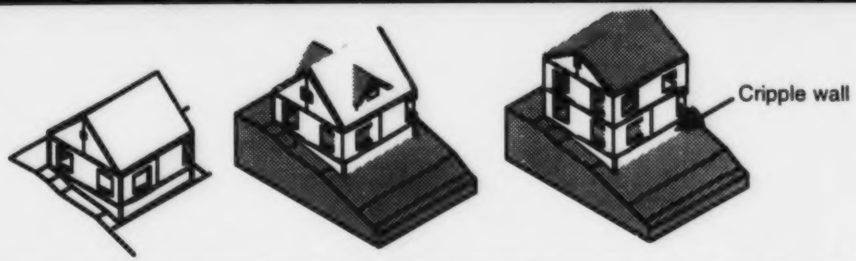
Figure 4B - 1:
Various Forms of Bungalow (1 storey)



- **The Cripple Wall House:**
  To raise the wood frame above the adjacent ground, to provide windows for basements, or to reduce excavation costs, houses are often built with the lowest wood floor supported on short wood cripple walls. The height of cripple walls can vary from less than 450 mm (18") to almost a full storey, in places such as Vancouver and Victoria. The resulting house presents some of the greatest challenges for earthquake upgrading. The wood frame cripple wall is often constructed with little or no bracing. In an earthquake, it is as if the entire house above is sitting on a series of dominos (the studs), which may not be braced to each other to form a diaphragm. Also, the cripple wall may not be well connected to the foundation below or the floor structure above. Little wonder that as much as three quarters of the damage, injury and death in significant earthquakes has been attributed to the failure of cripple walls.

  This form of house may be built as the bungalow, split level, or multi-storey house.

Figure 4B - 2:
Cripple Wall House (shown in bungalow, 1-1/2 storey and 2 storey house types)



RECOMMENDATIONS

The Bungalow:

- As the bungalow is built low to the ground, it is probably the safest house type from a seismic standpoint.
- To enhance its natural resistance to earthquakes, upgrade the seismic details. Information about foundations, cripple walls, main floor walls and reinforcing around openings may be utilized in the upgrade of this type of house.
- Determine the quality of the workmanship used in the construction of the existing house and the nature and condition of the building materials.

The Cripple Wall House:

As the cripple wall itself is the weak link in the house's seismic resistance, concentrate efforts on increasing the strength of that area, by:

- Properly fastening the cripple wall to the foundations below and the floor and structures above,
- Bracing the cripple wall so that it acts as a continuous, resistive structure rather than a series of weak, domino-like studs.

For a more comprehensive discussion of cripple walls, refer to Chapter 4, Section C, page 102.

CONDITIONS TO CHECK

- **The Taller House - One and a Half, Two or Three Storeys:**
The building codes that govern most housing construction in Canada permit the construction of houses of up to three-storeys plus basement. Especially in high land cost urban areas, taller houses are becoming the norm, with roof peaks often more than 10 m (33 ft) above the ground. Many older houses in urban areas also test these height limits.

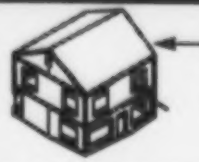
The heavier the building, and the higher the weight is above the ground, the greater the damage potential. For example, a three-storey house with a clay tile roof and masonry chimney will be much more prone to damage than a two-storey house with wood shingles and a metal chimney. The size and shape of the building, as well as the nature and location of both structural and non-structural elements, have a great influence on its performance in an earthquake:

Structure weight (called dead load), roof snow, rain, and wind loads
\+ Third floor dead load, wind, furnishing and people loads
\+ Second floor dead load, wind, furnishing and people loads
\+ First floor dead load, wind, furnishing and people loads
= Loads acting on cripple walls and foundations.

All of these loads may be imposed on a structure just when an earthquake strikes.

Figure 4B - 3:
Various Forms of 1-1/2 to 2 Storey Houses

1-1/2 storey gable roof & dormers, with living space within the roof volume



2 storey construction with gable roof over attic

- **The Split Level House:**
Split level houses are often weaker than other types of houses of similar character. This is because the juncture between the split levels is often constructed as a series of cripple walls with structure framing into them from both directions at different levels. These cripple walls are usually not built as braced walls to resist lateral movements induced by earthquakes. In an earthquake, two things happen:

  - The floor loads from two different heights and directions tear the cripple wall juncture apart; and
  - The house acts somewhat like two separate houses built close together, with the upper and lower roof levels pounding against each other, causing excessive damage.

Figure 4B - 4:
The Split Level House

A variety of arrangements exists. This sketch illustrates a garage 1/2 level below the main floor, with habitable space 1/2 level above the main floor

RECOMMENDATIONS

The Taller House:

- If a vertical extension is contemplated, expect to reinforce the existing wood structures and foundations below to compensate for the additional seismic loads it imposes. To successfully resist seismic forces, the design must exceed the basic requirements of the building code in force.

The Split Level House:

- Expose the framing of the wall between the split levels and upgrade it to be a lateral braced wall, that is, treat it the same as an exterior structural wall.
- Ensure that the wall between the split levels is seismically connected to the foundations and that the foundations are seismically engineered and on good bearings.

Item #

CONDITIONS TO CHECK

B3 — **GEOMETRY OF THE HOUSE**

The shape of a house, as well as the nature and location of structural elements, has a great influence on its performance in an earthquake.

B3.1

❑ **Shape:**
The shape of a house, as well as the nature and location of structural elements, has a great influence on its performance in an earthquake. Simple, symmetrical building shapes resist earthquake forces more successfully.

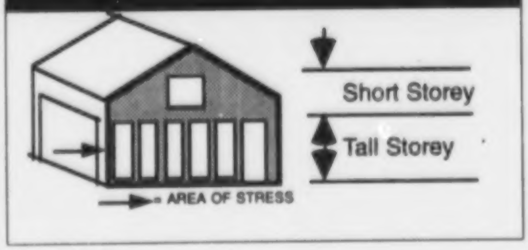
The earthquake stresses that a house must resist are additive. The taller a house, the more stress it will experience, other factors being equal. Force is transferred from the roof to the upper storey(s); the lower storey receives the stress from the upper storeys and the roof; and the foundation receives all the forces from above.

Simple and symmetrical plans, which provide for an even distribution of braced walls as well as nearly continuous floor and roof (horizontal) diaphragms, will suffer reduced damage due to torsional racking. However, more complicated house shapes, that often represent a higher quality of house, can also successfully weather earthquakes if built with better materials, construction techniques and attention to seismic details.

B3.2

❑ **Unusual Storey Height:**
If one of the storeys in a house is of greater height than the others (for example more than 20 per cent greater), the house will be subject to greater earthquake stresses than a house where the storeys are of the same height. An unusually high floor to ceiling height may also create a "soft storey" effect (see Chapter 4, Section B, page 78).

Figure 4B - 6:
Unusual Storey Height

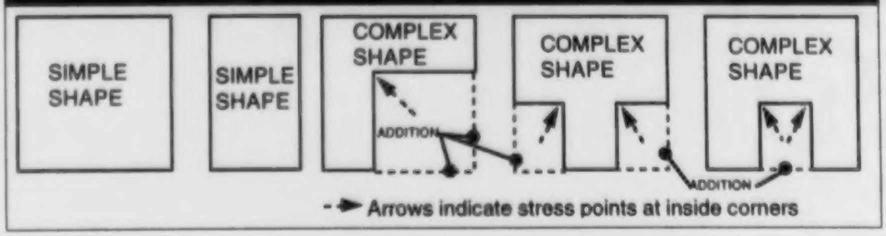


RECOMMENDATIONS

❑ **Shape:**

- If an addition is contemplated, try to use the opportunity to improve the symmetry of the house.
- If the addition creates an asymmetrical condition, strengthen the connections between the addition and the existing house to resolve the concentrated stresses.
- Or, re-evaluate plans to determine if a design plan with better seismic characteristics can be found.

Figure 4B - 5:
Simple Shapes



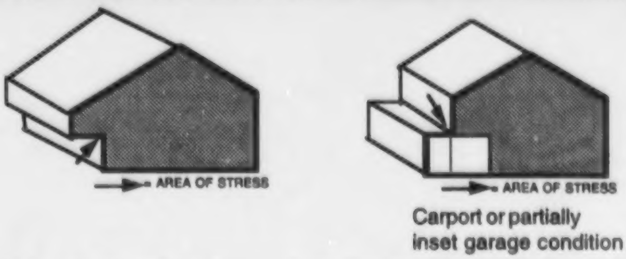
❑ **Unusual Storey Height:**

- Upgrade the connections between the high storey and those above and below, and increase the stiffness of the high storey.

CONDITIONS TO CHECK

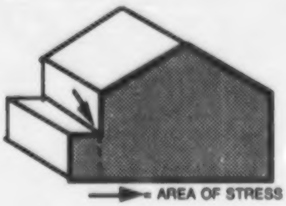
Item #	
B3.3	❑ **Overhanging Storeys (Cantilevers):** If there are conditions where upper, overhanging storey corner columns do not continue to the ground, these will result in increased loads imposed by overhanging storeys, increasing stresses on the storeys immediately below and foundations. This condition often exists in connection with carports or garages, where the storeys above bear in the middle of the garage. Seismic insurance risk evaluation programs, which are now becoming more commonly applied, attach a greater risk factor to a substantial overhanging storey.

Figure 4B - 7: Overhanging Storey and Cantilever



B3.4	❑ **Setback Storeys:** Where upper floors of the house are set back from floors below, structural walls may not carry directly through to the walls below and are more subject to damage in an earthquake.

Figure 4B - 8: Setback Storey



RECOMMENDATIONS

❑ **Overhanging Storeys (Cantilevers):**

- Consider the construction of columns below the projecting floors, structurally connected to the floors of the overhanging storeys, to new foundations below, and braced to the main structure.
- Where columns are not feasible or desirable, such as in the middle of a carport or garage, diagonally brace the overhanging element back to the main frame, especially where a new foundation is not possible. In this instance, the main frame will need strengthening to withstand the added loads.
- In the case of a carport or garage, the interior face of the structure is often unfinished and/or exposed. This affords an opportunity for bracing the walls of the open space, somewhat alleviating the overhanging storey condition.

❑ **Setback Storeys:**

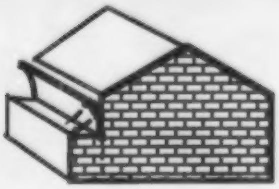
- Explore the feasibility of carrying the setback structure through the floors below to firm bearing.
- Evaluate the structure supporting the setback, and strengthen as necessary.
- Maintain the waterproofing on the exposed deck. Check for water penetration and condition of deck material, joist, and walls both above and below the deck.
- Upgrade the strength of the roof/deck where the floor above is set back. Upgrading will improve the structure's overall performance and also protect the space below from collapse of the setback wall or its cladding.

Item #

CONDITIONS TO CHECK

If the exterior finish material of walls on setback areas is masonry, special problems may exist. Masonry walls located at setback storeys are often supported on wood structural members, rather than steel members as required by most Canadian building codes. These wood members may not be adequately sized to support the weight of the masonry, let alone the forces in an earthquake.

Figure 4B - 9:
Masonry Setback Walls



B3.5 ❑ **Roof Junctions:**

Often roofing materials and flashings, including those used to waterproof decks, deteriorate more rapidly where they intersect with walls, other roofs, or terminate. In these locations, debris, snow and ice build up, making these areas more exposed to abrasion. They are areas where water ingress and structural deterioration often first occur.

In addition, in colder areas, snow builds up at these junctions, making them more susceptible to collapse if an earthquake occurs while they are heavily loaded.

RECOMMENDATIONS

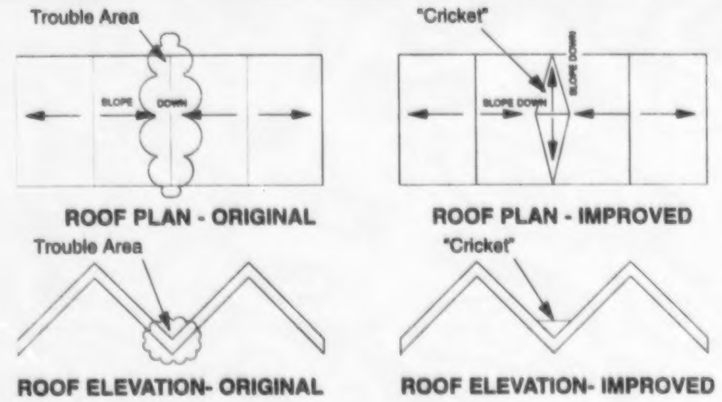
Masonry loads supported or restrained by wood walls have historically been affected during earthquakes. Masonry may break away from the wall or the load may cause the adjacent wood-frame wall to collapse.

- Support masonry on steel support angles (stainless or hot dipped steel) to replace wood.
- Consider whether the masonry is in an isolated enough location to allow it to fall off without causing structural damage or injury.

❑ **Roof Junctions:**

- Consider the use of zinc strips at the peaks of wood shingle/shake roofs, which help reduce the accumulation of mold and mildew on the roofs. When re-roofing a wood roof, use preservative treated shingles.
- Avoid sloped roof conditions that help snow, ice and debris to accumulate. Where these already exist, build up the areas with "crickets" prior to re-roofing, to reduce this form of wear and tear on the structure.

Figure 4B - 10:
Overhanging Storey and Cantilever



Item #

CONDITIONS TO CHECK

B4	MATERIALS ON THE EXTERIOR
	Because of inherent properties, some building materials perform better than others when subjected to the stress of earthquakes.
B4.1	❑ **Wood:** One of the circumstances that saved Anchorage from significant loss of life during its major earthquake was the fact that most of its housing was constructed in the form of plywood "boxes." The inherent strength of a large sheet material was critical to the preservation of life and property. However, most wood finishes on houses consist of small width, random length boards, horizontally, vertically or diagonally applied. These have little strength individually or in combination, due to their thin profile, random fibre alignment and difficult-to-predict nailing. On the plus side, wood sidings are probably the lightest weight finish available, minimizing the stress placed on the house frame in an earthquake.
B4.2	❑ **Masonry Veneer:** Masonry veneers are wall claddings such as clay and concrete brick, natural and artificial stone, and concrete block, which are attached to the wood frame of the house, on either the outside or inside. These claddings are used as finishes on walls and for decorative accents over doors and windows. Masonry veneer is an appealing architectural feature, but is susceptible to earthquake damage. The fundamental structural strengths of most types of wood-framed houses are about the same. Veneers themselves do not support the structure or contribute to the strength of the frame but, due to the weight of masonry, their loads have great impact when transferred to the structure of the house. During an earthquake, the additional weight of the masonry generates forces that can cause serious damage to the structure, as well as damage to the veneer itself.[1] Damage to the veneer is often caused by weak connections with the wood frame, which cause the veneer to crack or be torn away from the frame during the tremor. The connections between veneer and frame are usually made by metal ties. The absence of these ties, their condition, and their placement are all important factors contributing to the performance of the connection. Poor quality mortar is another cause, although a less important factor in the damage to masonry veneers. In an earthquake, the danger from falling masonry is very real. If masonry veneer is not installed using appropriate seismic details and good workmanship, veneered houses may suffer greater damage than those with other forms of cladding, including stucco. Multi-storey veneered houses are especially vulnerable.  Where falling masonry would constitute a hazard to a house, its occupants, or neighbouring houses and their occupants, upgrading, replacement or removal are the responsible options.

RECOMMENDATIONS

❑ **Wood:**
Whenever wood finished structures are repaired, an opportunity arises to replace the wood or its underlayer. In accessory buildings or where not sight-exposed, consider a treated plywood finish in full sheets. In more visible areas, replace the underlayer with plywood (minimum thickness 13 mm, 1/2") and ensure that there is a good moisture barrier such as heavyweight building paper.

Take care to ensure that exterior finishes do not prevent the wood frame or underlayer from "breathing," that is, getting rid of excess moisture, which may have been built into the structure during a wet construction season, or which may have leaked into the structure. Most "leaky buildings" arise from water trapped inside walls without a means of egress, resulting in the deterioration of the supporting structure.

❑ **Masonry Veneer:**
A well-built masonry wall has three key aspects to its design and construction:
- It keeps water out of the wall structure behind;
- It allows for movement, including wood frame shrinkage, wind loads and, of course, seismic stresses;
- It includes durable, highly corrosion-resistant ties, adequately spaced, to resist lateral forces without becoming brittle.

Unless professionally designed and inspected, avoid placing masonry where it could fall on people, block exits, or cause severe damage to the house or adjacent structures.

Ties
- The reaction of masonry veneers in an earthquake is a response to its mass, its connection to the frame of the house, and the characteristics of the frame itself. For example, because stone veneer is usually heavier than brick and is placed in irregular patterns, it must be even more frequently attached to the structure. Veneers are secured to the framing with horizontal ties. They are also supported vertically on foundations or steel shelf angles attached to the house frame.
- All anchorage and ties should be fabricated of stainless steel metal or hot dipped galvanized metal. The seismic restraint should be engineered to withstand a horizontal force equal to twice the weight of the veneer. There are also special "upgrade" ties available to secure existing veneers to their back-up structural systems.
- It is recommended that one anchor be placed at least every 0.13 m^2 (200 in^2) for veneer less than 100 mm (4") thick. For veneer with thickness exceeding 100 mm (4"), such as block or stone, it is recommended that one anchor should be used every 0.1 m^2 (144 in^2).
- Veneers on wood frame walls should not exceed a height of 4.5 m (15 ft) without the design involvement of a professional. It is not advisable to cover large areas, such as an entire wall, with stone veneer. The very probable failure of the heavy veneer can seriously damage the frame of the building and be a hazard to adjacent property or to people nearby. Of course, small and low veneered areas, such as partial walls and foundation coverings, do not present such hazards.
- It is important to verify the presence, condition, type and placement of ties. Ties are of metal construction, traditionally (although inadequately) constructed of corrugated, galvanized light gauge steel. If one can expose an edge or corner of a brick wall, or open its top, the presence and approximate spacing of any ties may be revealed by flashlight. Ties may also be located using magnetic detection.
- In both new construction and in renovations, use adjustable galvanized or stainless steel ties, which are significantly stronger than traditional corrugated ties.

Mortar
- Weak mortar can be readily recognized by its tendency to scrape away easily and to crumble between the fingers. Scrape a key across the mortar, and if the mortar crumbles away easily, it is very likely to fail during a quake. Weak or damaged mortar can be repaired in a process called repointing, in which loose or soft mortar is cut out and replaced.
- For either repointing or new work, masonry veneer walls should have a high bond, low strength mortar and be anchored to the structural walls with ties engineered for seismic loads.

Item #

CONDITIONS TO CHECK

Item #	
B4.3	❑ **Stucco:** Stucco, which is a cement-based finish, is a brittle material. However, if applied to a structure designed to resist earthquakes, using details developed for seismic conditions, and with quality workmanship, it will seldom fail or even fracture. Unfortunately, stucco is often applied to houses that have few braced walls and rely on interior drywall or plaster for additional seismic resistance. These interior finishes do not provide enough additional strength to withstand earthquakes without significant deformation of the structural framing. When the frame deflects, it causes the stucco to crack and break. Damaged stucco is not only expensive in itself to repair, but it is a reliable indication that structural damage has occurred, which would also require repair. Multi-storey stucco clad houses without seismic bracing are especially susceptible to damage because the relatively heavy stucco finish causes greater movement of the wood frame due to the greater inertia of the upper floors.[2] Minor stucco damage tends to occur around doors and windows, where the stress paths are interrupted by the openings and the earthquake forces become concentrated. Severe damage shows up as large cracks and spalling of wall surfaces (that is, they fall off). Wire mesh-reinforced stucco contains some shear strength, but values vary a lot with the type of mesh reinforcement, the way it is attached to the frame, and the thickness and quality of the stucco itself. Also, most of stucco's shear value is lost when it cracks. Wire mesh and other types of stucco lath should not be thought of as a substitute for seismically braced walls. A high quality three coat stucco finish, installed on metal lath, has strength equivalent to a 6 mm (1/4") plywood sheathing.[3]
B4.4	❑ **Exterior Foundation:** The foundation is a source of failure if it is constructed of: • brick or stone or un-reinforced concrete block; • concrete that appears to be crumbly; • foundation materials that have significant cracks. Mortar alone does not have enough strength to keep masonry foundations together during an earthquake. Crumbling and porous concrete has similar deficiencies in strength. None of these will be strong enough to prevent the anchors connecting them to the wood frame above from pulling out in an earthquake. The large majority of foundations for existing houses have no steel reinforcement, and most Canadian building codes still do not require reinforcement today. Unfortunately, even sound foundations will experience failure during severe earthquakes if they lack steel reinforcing, or do not possess footings that extend to bearing soil, particularly in clay-like soils and on slopes.[4]

RECOMMENDATIONS

❑ **Stucco:**

- Stucco systems can be constructed to have good resistance to seismic damage. Prior to repairing or adding new stucco, ensure that the bearing surface beneath is/remains sound and dry. To reduce the incursion of moisture to that bearing surface, apply a moisture barrier over it. Prior to applying the stucco, fix a heavy galvanized welded wire mesh that has been appropriately lapped and nailed to the structure of the house. Specifically, use 1.6 mm (16 gage) lath, applied with at least 100 mm overlaps. Increase the laps to 150 mm (6") at all corners, and mount directly to the building frame with 16-gauge staples every 150 mm (6") vertically and 400 mm (16") horizontally. The rule of thumb is to apply a minimum of 20 nails per square metre (10 ft²) that penetrate at least 25 mm (1") into the wood structure. Carefully apply the three coats of stucco application to achieve a minimum finished thickness of 20 mm (7/8").

- The earthquake damage around doors and windows may be reduced by the addition of interior or exterior plywood shear walls. This should not only control the fractures around the openings but also minimize the damage to the rest of the stucco covering of the building.

- Stucco practices vary widely in detail in various areas of the country. However, stucco is the exterior finish that appears most susceptible to water incursion, hence local building officials or design professionals should be consulted for the best local practices.

❑ **Exterior Foundation:**

- Undertake a thorough examination of the construction and condition of materials used in the foundation. Renovation or repair work that exposes foundations provides an opportunity for assessment. Examine exposed foundations carefully for deterioration or poor quality materials or workmanship.

- Whenever contemplating an addition, ensure that new foundations are seismically designed, with steel reinforcing, and constructed on firm bearing.

- Upgrade foundations wherever they are not designed to provide good seismic resistance.

For a discussion of foundations, see Chapter 4, Section C, page 82.

CONDITIONS TO CHECK

Item #

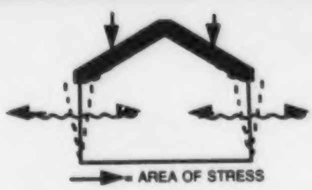
B4.5

❑ **Heavy Roof Loads:**

- The higher the weight of a building sits above the ground, the greater the potential for damage. For example, a three-storey house with a heavy tile roof will be much more prone to damage than a two-storey house with wooden shingles. Heavy snow or ice loads also increase the hazard. In fact, snow often piles up asymmetrically, which further increases the roof stresses during earthquakes.

- Heavy roof loads place stress on a house at the location furthest from the ground, greatly increasing the stress on the frame's connection to the foundation.

Figure 4B - 11:
Roof Stresses

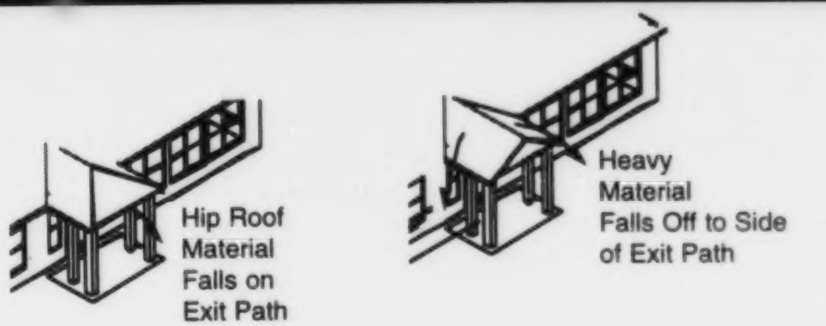


RECOMMENDATIONS

❑ **Heavy Roof Loads:**
There are several methods to overcome the hazard caused by the combination of height and weight.

- A simple approach is to avoid the use of heavy roofing materials. There is usually a light material that will do a good job.
- The use of heavy traditional materials (slate, or clay and concrete tile) should be engineered and installed for seismic resistance. For example, the supporting roof structure must be stronger and roofing units must be thoroughly attached to the structure.
- Ensure that heavy roof finishes, snow and ice will not fall onto an exit pathway. If this appears possible, revise the roof planes to create a safer condition. The configuration has a direct influence on the hazards from roofs, especially in heavy snow load areas.

Figure 4B - 12:
Roof Forms to Control Collapse



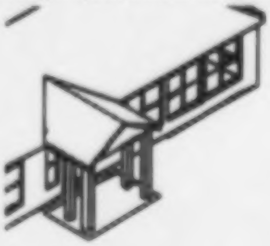
Item #

CONDITIONS TO CHECK

B5	APPENDAGES TO THE HOUSE

Elements attached to the house often fall during earthquakes.

B5.1 ❑ **Canopies, Porches and Decks:**



Open-sided appendages to a house such as carports, elevated porches, verandas and sun decks generally contain few solid walls. Typically they have only one solid wall (usually a wall of the main house), with wood columns, often built up of small dimension lumber, supporting the sides and front. Furthermore, the column loads may be haphazardly distributed across the deck surface below and there may be no direct load path to the foundations. Foundations themselves are often shallow and unreinforced.

This type of structural system will rack easily and provides very limited resistance when subjected to seismic forces. These structures often collapse in earthquakes because the components are lightly structured, poorly connected to each other and to the main house, and because the deck or foundation on which the elements sit is of light non-seismic construction. They are often built without any seismic resistance.

If canopies, porches or decks are part of the exit path, they must be constructed to resist an earthquake and to protect people from falling debris. If not in an exit path, or threatening one in the event of their collapse, then upgrading may not be necessary, provided the home-owner accepts the likelihood of total collapse and loss of these elements in an earthquake.

B5.2 ❑ **Roof-Mounted Elements:**

Common examples of roof mounted elements include antennas, solar collectors, heating units and air conditioners.

The larger and heavier the element, the more likely it is to be affected by an earthquake. It is common to attach an element, such as antenna, to the upper part of a chimney, a parapet or even a fascia. Unfortunately, these building components are the same ones that are also likely to fail in an earthquake. So, attaching an antenna to a chimney, for example, actually increases the probability that the chimney will fail.

RECOMMENDATIONS

❑ **Canopies, Porches and Decks:**

- Add bracing to the open faces of the structures to provide stability. If part of each open face can be enclosed, then braced walls may be used. The braced shear walls must be connected to engineered foundations below with hold-down anchors and with steel straps connecting the walls to the beams above.

- Reinforcing for faces that must remain open, such as carport entrances, can be done by providing narrow shear walls on each side of the openings. Where shear walls are not an acceptable solution, brace the spaces between the columns by adding diagonal steel bracing in an 'X' pattern. These can be fabricated of steel rods with turnbuckle adjustors. If walls or 'X' bracing are too obtrusive, knee-braces might adequately strengthen the frame corners. Regardless of the solution considered, details of bracing systems should be designed by a structural engineer.

- Ensure that the appendage structure is securely connected to the main house. Ensure that the columns are of adequate size and are securely connected to the foundation and to the structure (beam) above. Confirm that the foundations are adequate for the loads.

- Refer to Chapter 4, Section C, pages 82 and 130 for detailed information.

❑ **Roof-Mounted Elements:**

- Elements, such as antennae and solar collectors, should be well-braced and are best located either in the middle of the roof, or preferably, along the wall of the house.
- Brace elements back to the main structure, ensuring that the main structure is strengthened to accommodate the additional loads.
- Strengthen adjacent roof and wall areas onto which the element might collapse, with the aim of preventing the collapsing of other roofs or walls.
- If collapse of the roof-mounted elements appears inevitable, consider removing them, or replacing them with a lighter weight, stronger structure. Keep your own, and your neighbour's, emergency exit paths away from these elements.
- Remove all elements, including masonry chimneys, which are no longer in use.

Item #

CONDITIONS TO CHECK

B5.3

❑ **Masonry Chimneys:**

Traditional masonry chimneys, constructed of concrete block, brick and stone, are one of the elements of houses most frequently damaged during an earthquake, especially those parts that are free-standing above the roof line. Chimney failure, in some cases complete collapse, can occur. They have limited resistance to seismic movements because masonry is both heavy and brittle, and because most have not been built with reinforcing steel. Often they break away from the house frame, and because they have no reinforcing, and their mortar tends to be weak, they collapse as rubble next to the house. Chimneys that are reinforced typically lean away from the house if affected by a quake. If they collapse, they usually fall away from the house as a unit, often damaging an adjacent house.

Because the wood frame of the house and the masonry chimney are built as separate structures and using very different materials, they tend to respond to earthquake motions differently. Chimneys are typically provided with very little structural connection to the frame of the house. These factors cause them to pound against one another or pull apart during an earthquake.

Location of the chimney in the house affects how it performs during an earthquake. If it is located inside, near the centre of the house and does not extend up more than about 1 m (3 ft) above the roof, the damage is usually not serious. Because these chimneys are usually short, if they break at the roof line, they usually do not fall through the roof to cause damage inside the house. Where a chimney is freestanding inside the house or is located in a space with a "cathedral" (sloped roof) ceiling, the situation may be more serious, especially if the masonry element is more than one storey high. Where it extends more than about 1.5 m (5 ft) above the roof, it may go through the roof if it falls on the house. This is very likely when the roof is flat or has only a gentle slope. If the roof is steep, the pieces of fallen chimney tend to slide down the roof without penetrating to the interior of the house, but still present a hazard to those below. Chimneys that are located on the side or end of the house are more likely to fail because they have less support from the frame of the house. The taller the outside chimneys are, the more susceptible to damage, and the more damage they can cause.

A longer term and subtle condition caused by an earthquake or a series of small tremors is the fracturing and off-setting of the fired clay liners. This provides locations for flue gas to condense, leaving residue that leads to chimney fires.

Figure 4B - 13:
Two Examples of the Damage Resulting from Chimney Collapse

RECOMMENDATIONS

❑ **Masonry Chimneys:**
There are several reasons for the susceptibility of chimneys and a number of options to stabilize or strengthen masonry chimneys. It is difficult to reinforce an existing chimney. However, connecting the chimney to the frame of the house is one of the basic upgrades that can be done. If the house has a very tall chimney, removing the masonry entirely or at least that portion above the roof should be strongly considered.

Option 1: Connect Chimney to Structure
- There are two methods of tying chimneys to framing members such as top plates, ceiling joist, floor joist, roof rafters. One method uses steel straps that are embedded into the masonry and nailed to the floor and roof diaphragms of the building. The second uses long steel straps that are wrapped around the outside of the masonry and anchored to the masonry, then bolted to the wood frame. The chimney should be anchored to the house at the ceiling level and each floor level, as well as braced to the roof or another nearby structure where it is freestanding.

- For additional safety, install plywood in the vicinity of the chimney. That way, if the chimney falls, the plywood will help keep the masonry from penetrating through the roof and ceiling to the rooms below. Plywood could be installed on the roof (very practical if the house is being re-roofed), or on the underside of the rafters or even on top of the ceiling joist.

Option 2: Replace Masonry Chimney in Whole or in Part
- Given the tendency of masonry chimneys to break off at the roof line, it is worth considering the option of removing the masonry above the roofline and replacing it with a lightweight manufactured system. Often a decorative enclosure is built around the metal flue.

- Depending on the complexity, physical condition, and performance (does it draw well or give heat to the house) of the existing fireplace, it may be practical to remove the entire chimney, including the fire box. This decision is relatively simple if the fireplace is no longer in use or is in poor repair. It can be replaced with prefabricated sheet metal systems that are very light, strong, and flexible and do not cause any pounding or collapse damage associated with traditional heavy masonry. Because they are engineered and tested, an additional advantage is gained in that they draw very well. For traditional appearance, these engineered systems can be finished in a variety of veneers.

Option 3: Rebuild Masonry Chimney
- There are two methods of rebuilding masonry chimneys. External reinforcing can be installed, in the form of steel brackets or a cementitious coating containing wire mesh and fibre reinforcement. The alternative is to remove the existing chimney and fire box and replace it with a reinforced masonry fireplace and chimney designed for seismic resistance. Use of a professional engineer is recommended for either method, because a contractor seldom has all the information necessary to construct an earthquake-resistant structure.

Item #

CONDITIONS TO CHECK

Item #	
B5.4	❑ **Manufactured Metal Fireplace Chimneys:** Contemporary sheet metal chimneys, which are manufactured in sections and assembled at the site during construction, detach at the section joints during an earthquake. This failure is dangerous because it is not visible since the metal chimney is enclosed within the framing system. Subsequent use of the fireplace emits heat and flue gasses into the wood-framed chimney, causing potential hazards.
B6	**OPENINGS IN THE HOUSE EXTERIOR**
	Houses with large openings in their exterior walls frequently experience significant damage in earthquakes.

B6.1 ❑ **Soft Storeys**

Large openings occur for picture windows, patio doors, garage doors, carports, and outdoor covered areas. The term applied to this condition is the soft storey effect. It applies when the strength and stiffness is substantially less on one level when compared to the levels above. This happens when vertical framing elements are not brought down from the upper storeys to the foundation, but are stopped to provide for a large opening. The 'soft' effect is increased when the open floor supports a heavy structure above or the structure above acts as a shear wall. The forces acting on the house during an earthquake concentrate at the point where the structural system changes, instead of being uniformly distributed among all the stories. Split-level and multi-storey houses with the soft storey effect have become increasingly common since the 1950s. In stronger earthquakes, these buildings have suffered a disproportionate amount of damage.

The reason for this type of failure is easy to understand. The walls with large openings are inherently weaker than conventional walls. The openings, created by removing sections of wall, weaken a portion of the wall area that must carry and resist earthquake forces. During an earthquake, the building moves horizontally. In the absence of a continuous wall to resist the forces, the structure tends to twist and rack. In the case of a garage, the large opening often makes the house essentially a three-sided structure. This also occurs when the upper storeys of a house are supported on columns above an open carport.[5]

Soft storeys cannot easily withstand the resulting torsional forces, particularly under the additional weight of floors above. Under the stress of earthquake forces, the walls above the openings and at the corners of the openings severely distort as evidenced by severe cracking of interior and exterior finishes. If the distortion is severe enough, the 'soft' area and the portion of the house above collapse.

Figure 4B - 13:
Soft Storey

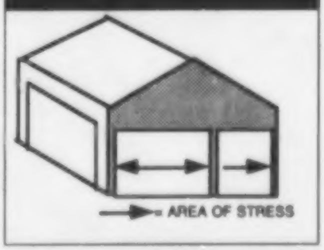


Figure 4B - 14:
Openings in Corners

RECOMMENDATIONS

To minimize damage and prevent collapses, the walls surrounding the 'soft' openings should be strengthened. Wall systems composed of drywall, standard framing, and exterior finishes are inadequate for this kind of stress. To increase the wall racking resistance, the panels adjacent to and above the opening must be reinforced. It is very important to use either moment frames or shear walls that are securely connected with the foundation below and to the floor system above. The walls must be continuously tied from the roof, to the walls and floors, to the foundation. Two means of achieving this, both of which should be designed by professionals, are laterally braced walls and steel moment frames.

Laterally Braced Walls:
Increased stiffness of the soft storeys can be provided by adding laterally braced walls at or near the open face. This can be accomplished by laterally bracing the walls on each side of the large opening or by adding them as buttress walls to the outside of the opening.

All walls of the house that are parallel to the large openings should be constructed as laterally braced walls. Steel straps and anchor bolts should also be installed to tie them to the roof or floors above and to the foundation. Strength requirements for laterally braced walls depend on the size and location of the openings. New braced walls should be installed with their own reinforced concrete footings.

A commonly-recommended upgrade is the addition of plywood sheathed braced walls of at least 1.2 m (4 ft) long at the corners of the house with large openings in the walls. If the lateral walls are less than 2 m (6 ft) long, the use of special anchors, called hold-down bolts, at the ends of the walls is recommenced.[6]

Of the various forms of laterally braced wall construction, those constructed with plywood sheathing provide the greatest strength. For a more complete discussion, refer to Chapter 4, Section C, page 108.

Steel Moment Frames:
Steel frames, each with reinforced concrete footings, can be added at the openings or even internally to the interior portion of the house. In engineered houses, it is common to stabilize large glass walls or large garage openings with steel frames, which take the place of laterally braced walls. The steel frames are constructed as moment resistant frames.

Steel frames are more expensive but do not require as much space as additional wood walls. Sometimes steel frames can be integrated into the space occupied by the original wood structure or exposed as part of the architecture of the house.

[1] Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., p. 95.

[2] Ibid., p. 92.

[3] Helfant, David Benaroya, (1992) "Seismic Bracing," *Advanced Framing Techniques, Troubleshooting & Structural Design*, The Journal of Light Construction, RR2 Box 146, Richmond, VT., p. 69.

[4] Helfant, David Benaroya, (1989), *Earthquake Safe: A Hazard Reduction Manual for Homes*, Builders Booksource, 1817 Fourth Street, Berkeley, CA, p. 20.

[5] Yanev, p. 134.

[6] Ibid., p. 138.

Section C
EVALUATING THE INTERIOR STRUCTURE

After documenting the property and exterior conditions of the house from the outside, the next step is to carefully examine and assess the structure from the interior. It is important that the structural elements that contribute to the seismic resistance of the house be in good physical condition and that they be adequately interconnected in order for the house to act as a "whole."

While performing this inspection, measurements of the foundations and each floor may be taken, which provide a start for the preparation of plans for upgrading. Drawings of the house help to understand the relationship between structural components, especially those that require upgrading to improve seismic resistance.

CONDITIONS TO CHECK

Item #	
C1	**FOUNDATIONS**
	The foundation is the first element in the house to experience the force of the earthquake and is the element that must endure the greatest forces. Quake movements are transmitted from the ground, through the foundation, and then into the wood structure of the house. The reaction of the structure and the contents of the house are then transmitted back through the foundation to the ground. The foundation supports and ties all the elements so they act as a unit to resist the earthquake. The strength of the foundation, the connection of the other elements to it, and its relation to the earth are all factors in its ability to resist earthquake forces. It is critical that the foundation survive, if the house is to survive.
	❑ **Assessing the Foundations:** Evaluation of the interior structure of the house to reduce earthquake hazards begins at the foundations. Diagramming the building's foundation provides an important aid for evaluating its structural characteristics. Here are items to be documented: • Does the foundation use any posts or individual concrete piers? • Is there a continuous perimeter concrete foundation wall? • Is there a foundation wall beneath all the main bearing walls of the house (both at the perimeter and interior)? • Do the foundation walls have footings that provide adequate bearing? • Does the foundation have steel reinforcing? • Does the foundation penetrate through the top soil and rest on rock or stiff soil? Guidelines on how to assess elements of the wooden structure, such as cripple walls and supporting walls, follow.

RECOMMENDATIONS

- [ ] **Assessing the Foundations:**
Undertake a thorough examination of the materials used in the foundation and their condition. If the foundation is constructed of wooden posts on individual concrete piers, or of unreinforced brick, concrete block or stone, it will not perform successfully during a strong earthquake. If it is constructed of concrete that is soft or crumbly or has significant cracks, there is also a strong possibility of failure.

A good test of the condition of the foundation is to drill a few test holes into the top of the suspect foundation and install some expansion type anchor bolts. If, after tightening the nuts, the bolts keep on climbing out of the hole or can be pulled out, the foundation is in poor condition. A simple check of the condition of mortar or concrete can be done by picking at it with a screwdriver. Soft materials will flake or spall. In these cases, either a complete or partial foundation upgrade is necessary.[1]

Item #

CONDITIONS TO CHECK

C1.1

❑ **Foundation Types:**

The foundations described below provide reliable seismic resistance. Unfortunately, many houses with foundations that appear to match these are not engineered and do not contain the necessary reinforcing steel and thus may not provide sufficient seismic resistance.

Figure 4C - 1:
A House that has Fallen off its Cripple Wall

RECOMMENDATIONS

❑ **Foundation Types:**
The earthquake resistance of foundations is governed by a few basic principles:[2]

- Foundations should be supported by solid ground, and the ground itself should have uniform structural characteristics. For example, the foundation walls should not be supported partially on stiff soil with the balance on landfill. The different reactions of the soil types during an earthquake can cause severe damage to the foundations and magnify the reactions to the structure it supports.

- Different types of foundations should not be used under the house. A common practice in house construction that does not perform well is the use of perimeter foundations with interior posts on individual concrete piers. Different types of foundations react differently to the ground motions generated by an earthquake. If the house is to successfully resist seismic forces, the foundation must provide uniform behaviour. This is most simply achieved using uniform construction systems, starting with the foundation.

- The type of foundation required for the house is determined primarily by the ground conditions under the building and conditions immediately adjacent. Selection of the foundation system should be the decision of persons knowledgeable in seismic structural design and the geology of the area.

Even when the foundations are seismically designed and perform successfully, faulty or insufficient connections with the wood structure can allow the house to fully or partially fall off its foundations. This aspect of the evaluation is discussed in Chapter 4, Section C, page 130.

Item #	CONDITIONS TO CHECK
	• **Continuous Tied Wall Foundation** In this common type of foundation, the steel reinforced concrete walls and footings provide uniform support under the main load-bearing walls of the building. The concrete foundation system is reinforced with vertical steel bars tied to the horizontal steel bars that are continuous through the foundation system. To provide good seismic resistance, it is important that the reinforcing steel wraps around the corners and junctions of the foundation. This type of foundation enables a building to move as an integrated unit during an earthquake; all the elements that compose the structure move together and thus damage is minimized. • **Mat Foundation (also known as floating foundation and slab-on-grade)** Resting directly on the soil, the reinforced concrete slab provides rigid and continuous support. The mat foundation is often ideal for buildings located on soft soils or landfill because of its ability to bridge over the pockets of soil that provide little bearing. During an earthquake, the slab and structure would move together evenly to resist serious cracking and warping. Slab dimensions and reinforcement size and position are a function of the soil conditions and the position of loads imposed by the structure. • **Drilled Pier or Caisson-Pile Foundations** This type of foundation is constructed of steel or reinforced concrete pilings set deep in the ground. These foundations are generally used in soft or unstable soils, such as landfill or wet areas. They provide support through the unstable soil to better bearing, which allows surface soils to settle and move without affecting the structure. This type of foundation is rarely used in house construction due to its complexity and cost.

Figure 4C - 2:
Continuous Tied Wall Concrete Foundation

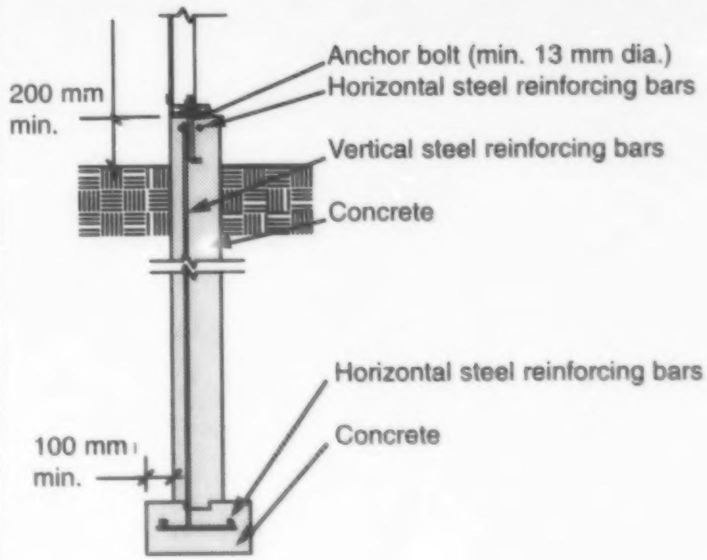
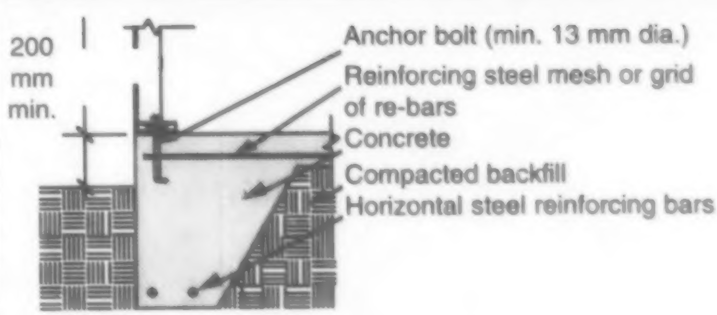


Figure 4C - 3:
Mat Concrete Foundation



Item #

CONDITIONS TO CHECK

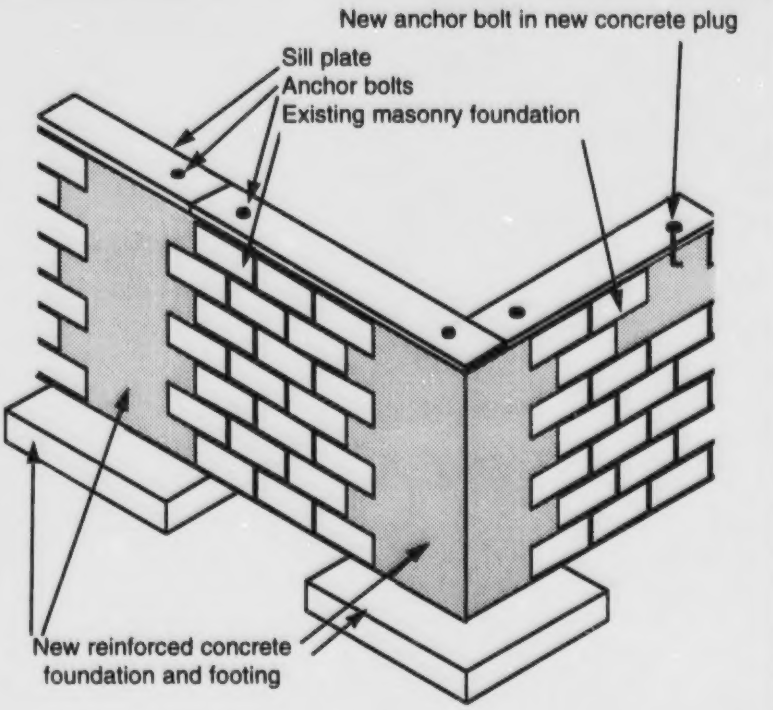
Item #	
C1.5	❑ **Masonry Foundations:** Foundations constructed of masonry are usually not seismically engineered and seldom are reinforced with structural steel. The ability of unreinforced foundations of stone, brick or concrete blocks to support the house structure above and to transfer seismic forces to the earth is poor. Although the individual masonry units may be strong, the mortar does not have enough strength to bind them together as a structural element during an earthquake. Even if foundations appear sound, they may not perform adequately during severe earthquakes because they do not have the ability to hold anchor bolts that restrain the wood structure of the house above, and they cannot successfully tolerate movements in the supporting soils below.

RECOMMENDATIONS

❑ **Masonry Foundations:**

- If foundations are made of brick, stone, or even concrete block, and have no steel reinforcing, the structural connection between the house frame and the earth needs to be upgraded. Consult a structural engineer specializing in earthquake design. There are several solutions to upgrading of foundations, but they are dependent on factors such as soil conditions, the geometry of the house, and the nature of other modifications being considered, as well as costs. Recommendations can include removing parts of the foundation and replacing it with an engineered concrete or concrete block system with steel reinforcing.

Figure 4C - 4:
Example of Masonry Foundation Upgrade



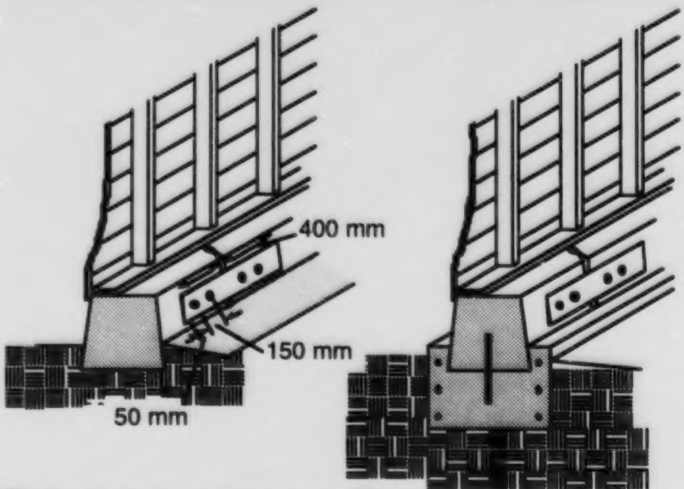
Item #	CONDITIONS TO CHECK
C1.6	❑ **Concrete Foundations:** Existing concrete foundations often contain cracks. Wide cracks of more than 3 mm (1/8") indicate the need for repair. These wide cracks are not to be confused with commonly seen "hairline" cracks that are caused by the shrinkage of concrete as it cures (dries). Wide cracks may signal serious distress in the foundation system and its ability to adequately support the loads. Building settlement is often due to the interaction between the structural loads and soil or water conditions at the site. If existing foundations need to be upgraded, they should be designed by a specialist engineer. This can involve reinforcing and deepening or widening the foundation in the area of the condition. If the cracks are associated with decomposition of the foundation concrete, the concrete will likely need to be replaced with new sections. In many cases, the underlying cause is faulty drainage at the foundation. While hairline cracks do not indicate significant structural damage, they should be repaired. Water ingress into the cracks may corrode whatever structural steel may be inside the wall and will, over time, lead to the decomposition of the concrete. The presence of steel reinforcing may be checked with high sensitivity metal detection equipment or X-ray equipment.

RECOMMENDATIONS

❑ **Concrete Foundations:**

- The techniques used to repair fractures in concrete depend on the causes of the cracks, which can be soil conditions, design loads, design of concrete mix, quality of placement, or hydraulic pressure (drainage). The cause of the cracking should be determined and resolved before repairs are undertaken. If the foundation does not have steel reinforcing, the crack may be cleaned and dried using compressed air and sealed by filling with epoxy or hand packed structural grout. The fractured area can be strengthened, to a limited degree, by installing a steel splint across the crack and extending beyond it a minimum of 400 mm (16") on either side. The splint is bolted to the stem wall of the foundation as shown in Figure 4C-2 on page 87. The repair of reinforced foundations is more complicated because of the necessity of chemically treating the rusted steel. The repair utilizes cleaning and epoxy injection techniques and is most successfully performed by a specialist.

Figure 4C - 5:
Repair to Existing Concrete Foundation



Ⓐ Steel splint over crack in existing foundation

Ⓑ Steel splint (as in A) with new supporting foundation

Item #

CONDITIONS TO CHECK

C2	WOOD-FRAME SYSTEMS

❑ **Diagramming the Framing System:**

Diagramming the framing system of the house is an important aid in evaluating the capability of the structure to resist seismic forces. Here are important structural relationships to look for and illustrate on the drawings:

- What type of frame system(s) is used in the construction of the house?
- How is the wooden structure connected to the foundations?
- Is the first wood-framed floor connected directly to the foundation?
- Are roof, upper wall and floor loads transferred directly to the walls below?
- Are the perimeter and interior walls (and columns) that receive loads from above supported directly by foundations?

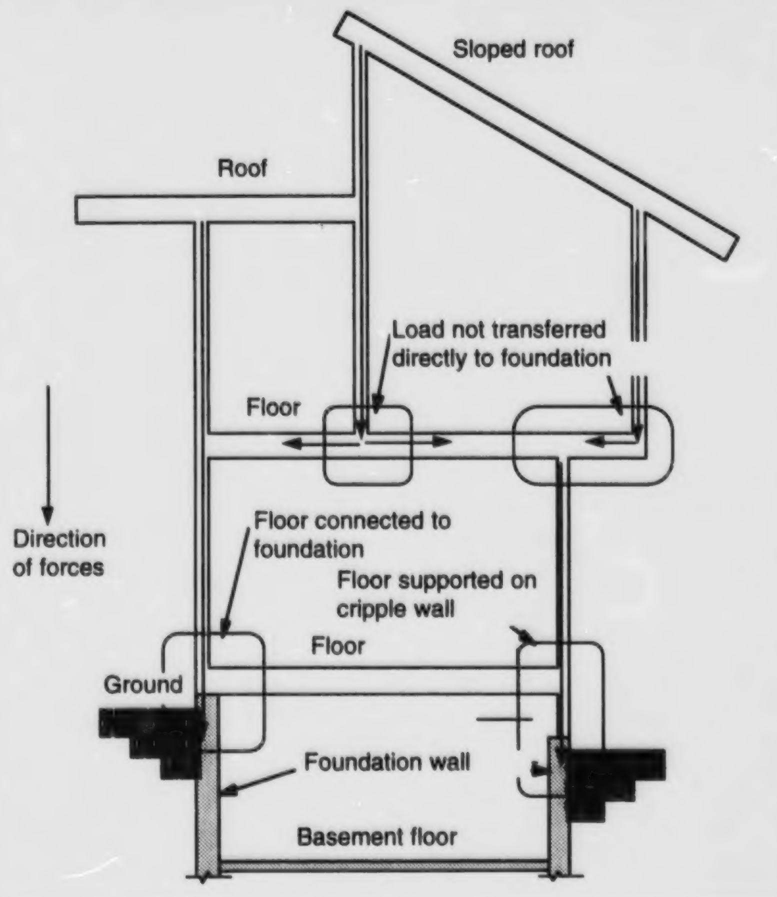
All of these questions are intended to help describe the extent of "continuous force paths" that exist for the house in question. A continuous force path is a direct vertical line from the top of a structure to the ground, along which forces including earthquake forces may be transferred from a structure to the ground. For example, where a wall sits on a floor without another wall immediately below, the force path is interrupted. Where a wall has openings cut into it for doors or windows, the width of the continuous force path is decreased by the width of those openings.

RECOMMENDATIONS

❑ **Diagramming the Framing System:**

This is a sample diagram of a house framing system in section. For a more complete example, including plans, refer to the case study in Appendix F.

Figure 4C - 6:
Force Transfer in a Sample 2 Storey + Basement House - Section View



Item #

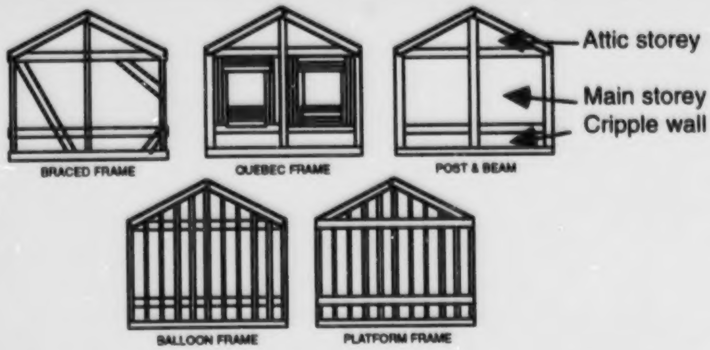
CONDITIONS TO CHECK

Item #	
C2.1	❑ **Frame Types:** The construction of houses has evolved in Canada over time in response to several factors: • the application of traditional construction techniques imported from abroad, mainly from Europe, • the changing characteristics of the wood available for harvesting and milling, both for the structural frame, the cladding, and other components, • the development of new wood products and construction techniques, primarily after the Second World War. A variety of framing techniques have been used to construct houses in Canada's earthquake hazard zones. They are: braced frame, Quebec frame, balloon frame, post and beam frame, and platform frame. Each has unique characteristics that must be considered when carrying out seismic upgrading. The most challenging type of frame to analyse is the composite, where different portions of the house are constructed differently. With a combination of types, it may be necessary to consult a structural engineer, as the *Guide* may not adequately deal with the complexities of multiple, non-integrated systems.

RECOMMENDATIONS

❑ **Frame Types:**

Figure 4C - 7:
Simple Diagrams Comparing Gable End Wall Construction of Typical Canadian Framing Systems



Item #

CONDITIONS TO CHECK

- **Braced Frame:**
This "traditional" form of construction is still used in some barn structures, but seldom found as a house framing technique after the 1950s. It is characterized by large dimension corner and intermediate posts, usually continuous from foundation to roof eaves; either full-length diagonal or upper and lower knee braces connected to the corner posts; upper floors supported on horizontal girts between posts; mortise and tenoned joints, complete with wood pins; stud infill between the posts often at approximately 400 mm (16") centre to centre; and horizontal sheathing, commonly of 1 x 6 tongue and groove. When built by skilled craftsmen and if in good condition, braced frames are exceptionally strong (the pinned joints may be three to four times as strong as steel connections).

- **Quebec Frame:**
This framing system is unique to Quebec, and is a variation of the braced frame. It is characterized by limited application of bracing and the use of miscellaneous 2" boards as both studs and sheathing to complete the walls between posts and girts. The infill boards are not usually lapped over corner posts, therefore make little contribution to the overall frame stiffness.

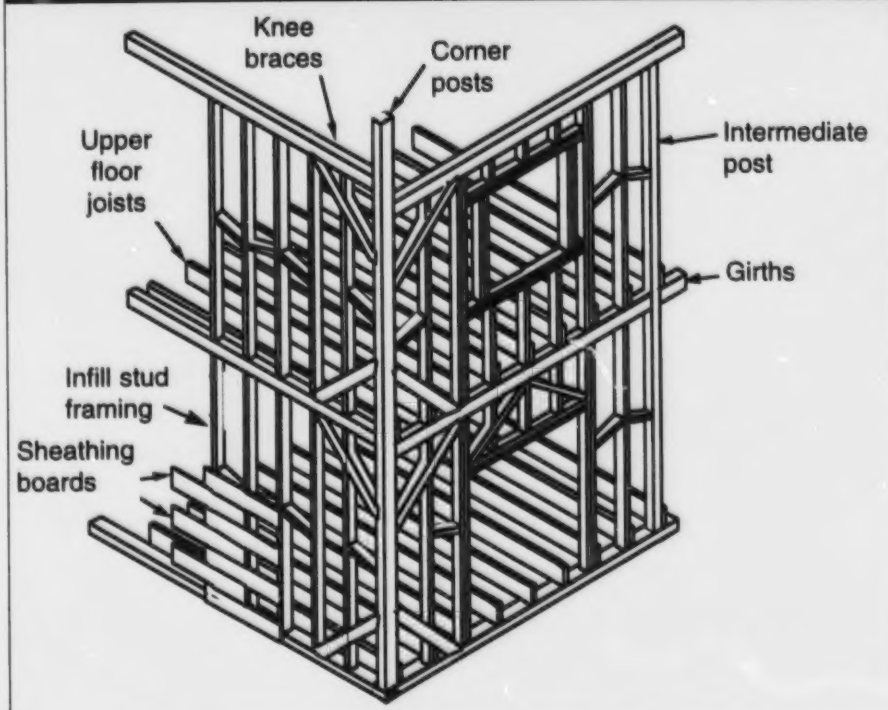
Figure 4C - 8:
Quebec Frame Circa 1975

RECOMMENDATIONS

- **Braced Frame:**
Where it is determined that lateral bracing is needed, follow the bracing techniques described in Chapter 4, Section C, page 108.

- **Quebec Frame:**
Upgrading a Quebec frame type for seismic resistance often includes the addition of lateral bracing (Chapter 4, Section C, page 108) and steel structural connections (see Chapter 4, Section C, page 126).

Figure 4C - 9:
Braced Frame



Item #

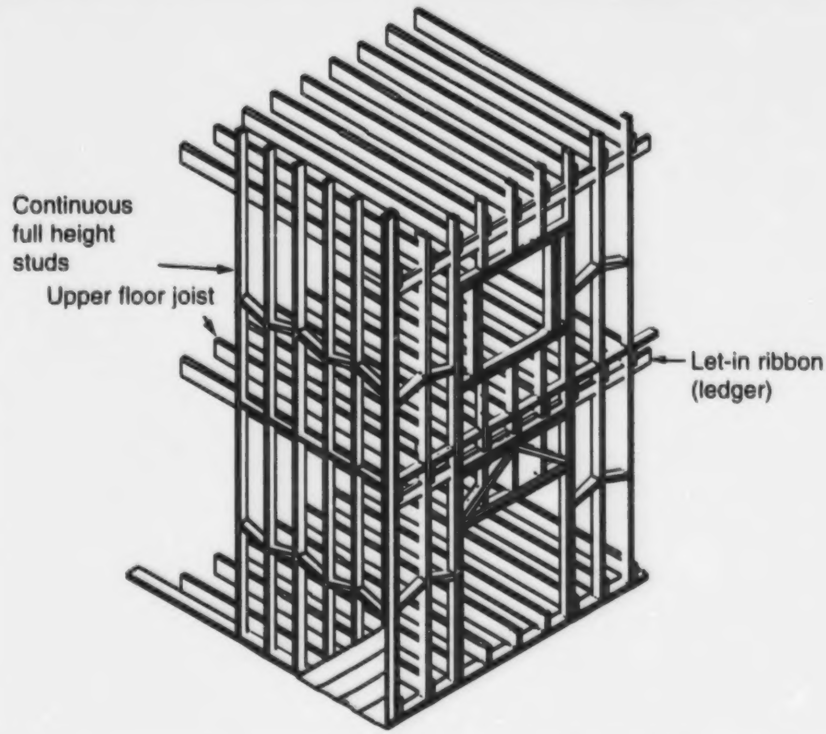
CONDITIONS TO CHECK

- **Balloon Frame:**
This framing system is the predecessor of today's prevalent platform framing, and is characterized by studs that run continuously from foundation to eave in height. Each stud carries its load directly to the sill of the foundation without benefit of any lateral distribution. This results in openings in the frame generally being aligned one above another, which also means that there is good potential for providing continuous laterally braced walls. Conversely, upper floor joists are supported on 25 x 200 mm (1" x 8") ribbon joists that are let into the studs (that is, cut in 25 mm [1"]), which weakens the frame and provides less floor diaphragm strength. The balloon frame itself has no lateral bracing. The rigidity of the house is dependent on the resistance supplied by the sheathing and finishes. Chief features of the balloon frame are the economy in the amount of framing lumber needed and the simplicity of construction. Balloon framing is seldom used today as studs of sufficient structural integrity are rarely available in lengths needed for more than a single storey. Ribbon joists are a specialized form of ledger, and ledgers are used in each type of frame system.

RECOMMENDATIONS

- **Balloon Frame:**
  The bracing techniques described in Chapter 4, Section C, page 108 are applicable and will mitigate the inherent seismic weaknesses of the balloon frame.

Figure 4C - 10:
Balloon Frame Construction



Item #

CONDITIONS TO CHECK

- **Post and Beam:**
  The light, open framework of unrestrained posts and beams characterize this framing method. Typically the roof and floors are made of 50 mm (2") thick wood decking supported on purlins and beams that are in turn connected to columns. Structural members are connected with steel connections or mortise and tenon joints. The structural members are usually left exposed as an architectural feature.

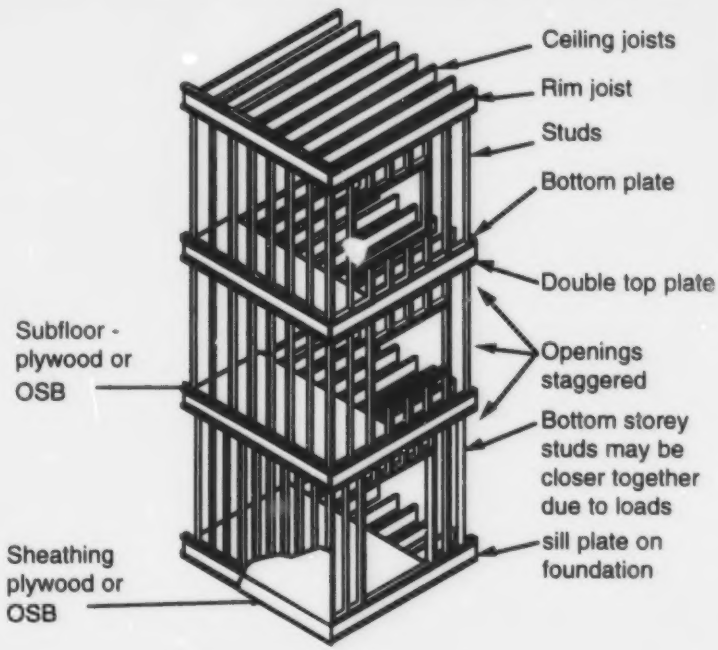
  Unlike other framing systems that can utilize their supporting walls as lateral bracing, post and beam requires that structural members be added to resist seismic forces. Bracing can be accomplished with wood or steel diagonal members or braced wall panels anchored to columns, beams and foundations. Seismic performance of post and beam houses is difficult to achieve and requires careful engineering to be successful.

- **Platform Frame:**
  This is the framing system used in the majority of homes built since the Second World War. Each floor is constructed as a platform consisting of a continuous header joist around the perimeter, into which floor joists are framed. A subfloor is nailed over top, usually consisting of plywood, and the resulting platform is used as a base to build up the next set of walls and floor. Wall framing is one storey high, thus each storey is a separate structural entity. The junction of wall and floor framing elements is a line of weakness and an area of potential structural failure. Typically, platform framing is constructed without bracing, relying on the continuous header joist, the sheathing, and finishes to provide stability.

RECOMMENDATIONS

- **Platform Frame:**
  This is the frame type that the recommendations of this section address most directly. The platform frame often requires upgrades for lateral bracing. Because the structure is discontinuous at each storey, it is also important to provide vertical ties at each floor level.

Figure 4C - 11:
Platform Frame Construction



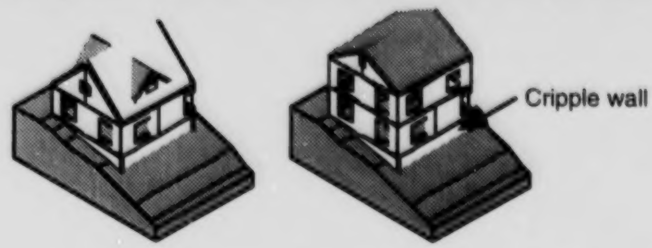
Item #

CONDITIONS TO CHECK

C3	**CRIPPLE WALLS**
C3.1	❑ **Cripple Wall Construction:**

Cripple walls are the short wood-framed walls that extend from the top of the foundation to the underside of the first framed floor level. The cripple walls are an extension of the foundation forming a "crawl space" for access to building services such as heating ducts and gas lines or a "basement" as part of the living area of the house. On sloping sites, cripple walls may be quite high if located on the downhill side of the house. In temperate climates such as Canada's west coast, where frost penetration is relatively shallow, cripple walls and short foundation walls combine to create habitable basements that are largely above adjacent grade. Cripple walls are also often found in split level houses.

Figure 4C - 12:
Cripple Walls on a Sloping Site



At the exterior, cripple walls are usually finished to match the remainder of the house. The details of cripple wall construction can often be seen from inside the house or crawl space, without the necessity of removing finishes. To provide adequate seismic resistance, the cripple walls must provide lateral bracing. Look to see if the studs are covered with plywood, or if diagonal sheathing or cross bracing has been installed. If the exterior of the framing is not braced with one of these materials, the cripple walls require strengthening. Even with these materials in place, without direct observation, one does not know if they have been nailed adequately to the studs.

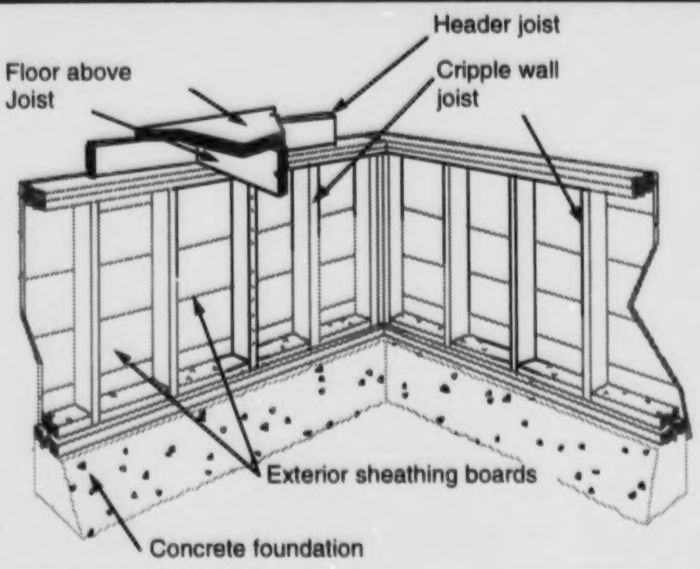
A very high proportion of earthquake damage to wood-frame houses is from structural failure of cripple walls. To provide adequate seismic resistance, the cripple walls must be laterally braced, must be firmly connected to the foundation below and the floor above, and the building materials must be in good condition. The weakest are those clad in horizontal wood siding, shingles, stucco or masonry. Those exterior finishes provide no effective lateral strength and thus the cripple wall can easily collapse. Because the interior of the house has many walls to resist the force of the quake, it is more rigid. The cripple walls, by contrast, are on the perimeter of the house and often there are no interior cripple walls to help, thus they are even more prone to failure.

Peter Yanev, author of *Peace of Mind in Earthquake Country*, estimates that as much as 70 per cent of all serious earthquake damage to older wood-frame houses would be eliminated by the upgrading of two basic conditions: the connection of the wood-frame system to the foundation and lateral bracing of the cripple walls.

RECOMMENDATIONS

❑ **Cripple Wall Construction:**

Figure 4C - 13:
A Typical Cripple Wall Installation - with No Seismic Upgrading



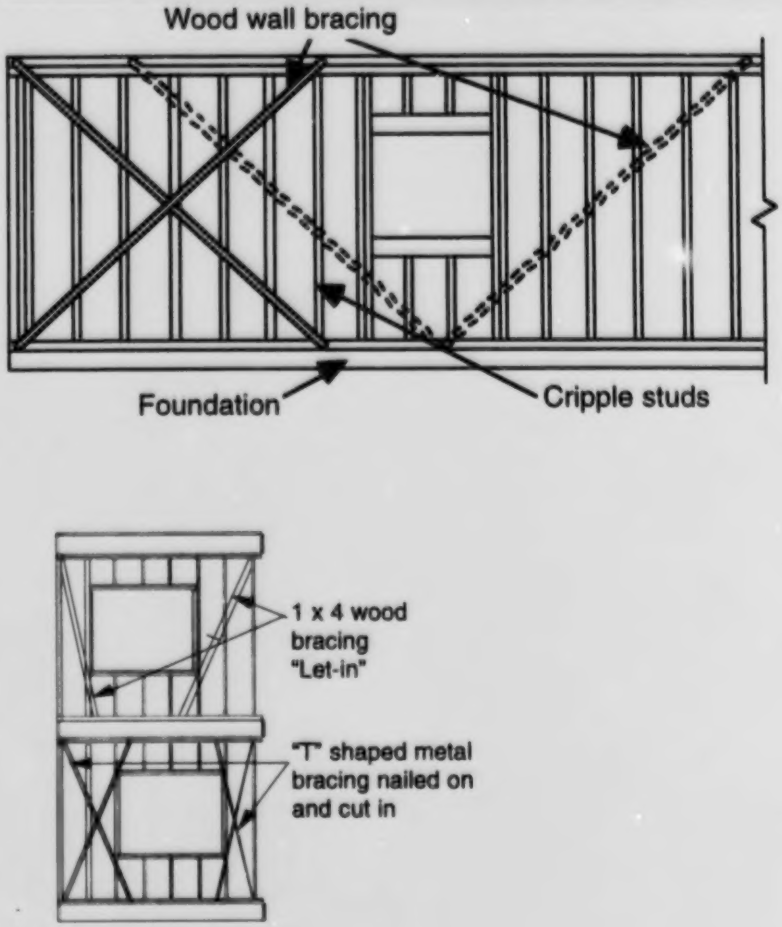
- Determine the bracing needs of cripple walls by checking the direction of the floor joists and the roof rafters or trusses. If all of these framing elements run in the same direction, then the bearing walls on which they rest definitely need to be seismically braced. Cripple walls are the critical elements in the transfer of structural loads to the foundation. A rule of thumb for determining the minimum length of a plywood braced cripple wall is to install 1.8 m (6 ft) of braced wall in each direction at each corner for a one-storey house. Install 3 m (10 ft) for two-storey houses, and the entire cripple wall in three-storey houses.[3] Refer to Chapter 4, Section C, page 108 for a discussion of braced walls.
- Cripple walls can be upgraded to provide lateral support by the addition of bracing on either the inside or outside to form plywood braced walls. Working from the interior saves the expense of first removing the exterior siding and later replacing it.
- In the process of bracing cripple walls, it is also important to replace any wood members that are not in good condition, for example, rotten, largely cut away by previous construction, with large, loose knots, cracked or extensively checked.

Item #

CONDITIONS TO CHECK

RECOMMENDATIONS

Figure 4C - 14:
Cripple Wall Elevation Showing Different Methods of Diagonal Bracing



- To build a plywood braced cripple wall, plywood must be fixed to the top and bottom plates, and each stud. The nailing pattern is important, and is described in detail in Appendix C, Technical Details. In a ventilated crawl space, cut openings in the plywood to match the existing ventilation. Also provide 40 mm (1.5") ventilation holes between each cripple stud. Place them about 100 mm (4") away from the top and bottom wall plates. This is to prevent the retention of moisture in the stud cavities.
- To further stabilize braced cripple walls, knee bracing can be added as part of the hazard reduction strategy. These braces provide moment resistance against the hinging action that usually occurs in lengthy cripple walls during strong quakes. A typical knee brace is 38 x 140 mm (2" x 6") bolted to a cripple stud about halfway between the sill plate and top plate. It extends up at a 45 degree angle to just under the subfloor and is bolted through the floor joist. Steel hold-down connectors should be added to the same stud to reinforce the stud to sill plate connection. Knee braces can be installed on cripple walls to be sheathed with plywood, by installing the braces first, blocking around them to provide support for the edges of the shear panels, and then cutting slots in the plywood so the sheets can be lowered down over the braces.[4]

Item #

CONDITIONS TO CHECK

C4	SUPPORTING WALLS

❑ **Assessing the Walls:**

To determine the contribution that walls provide to the stability of the house, draw a plan of each floor of the house to illustrate the structural walls (or use the plans previously developed in this chapter). For an illustration of an assessment, refer to the case study in Appendix F. Diagrams must illustrate all the supporting walls, both on the interior and on the perimeter of each floor level, and the openings through them. Supporting walls can generally be identified because they are continuous from floor to ceiling and they carry down to the foundation. The portions of walls providing lateral support do not have windows or door openings. A long wall with a door opening or large window is actually considered as two separate braced wall segments. Lateral walls on an upper level may have openings in the walls beneath them, but the ends of the walls (being considered as structural walls) must continue uninterrupted to the foundation.

When the laterally braced walls are drawn out, they should be reasonably evenly distributed and reasonably symmetrical throughout the plan. The house corners should have braced walls or a significant braced wall length near them. Factors determining the lateral wall requirements are the soil conditions, the building weight, the house geometry, the framing design and the seismic risk zone (which indicates intensity and duration). If factors of length or placement of braced walls is limited or unknown, consult a seismic professional for analysis and house-specific advice.

Strategically-positioned braced walls that are structurally connected from eves to foundation substantially reduce the damage to houses and contents. Well-built and maintained single-storey houses, even if clad with horizontal wood sheathing, should survive even a large quake. However, houses with cripple walls and two or more storeys should have reinforced walls to at least the second floor level. Houses of any height with cladding such as shingles, stucco, aluminum or vinyl are dependent on braced walls for seismic resistance. Conventional wall construction of interior plaster or drywall on wood studs is not strong enough to successfully resist a local earthquake. Such construction should be reinforced with additional lateral bracing. The greater the number of storeys, the more critical the lateral component becomes.

RECOMMENDATIONS

Figure 4C - 15:
Plan Showing Composite Force Paths for Larger Scale Drawings (See sample house from Appendix F)

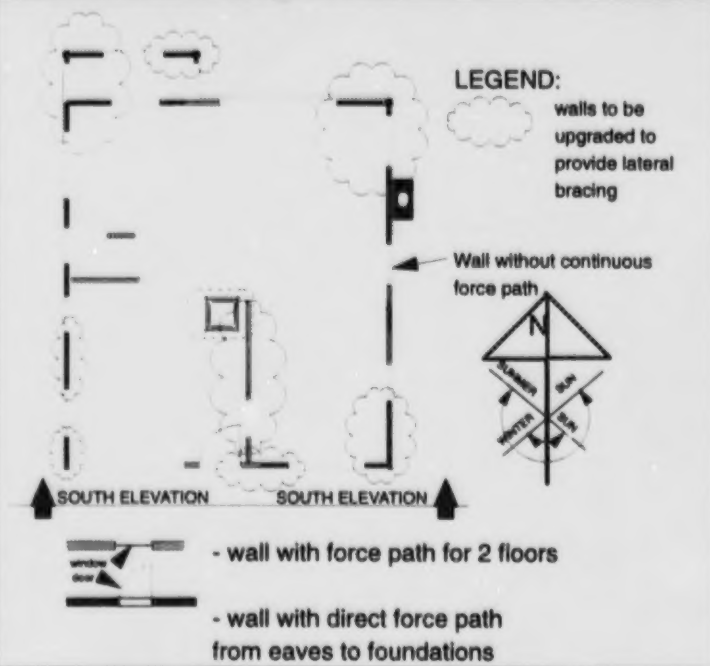
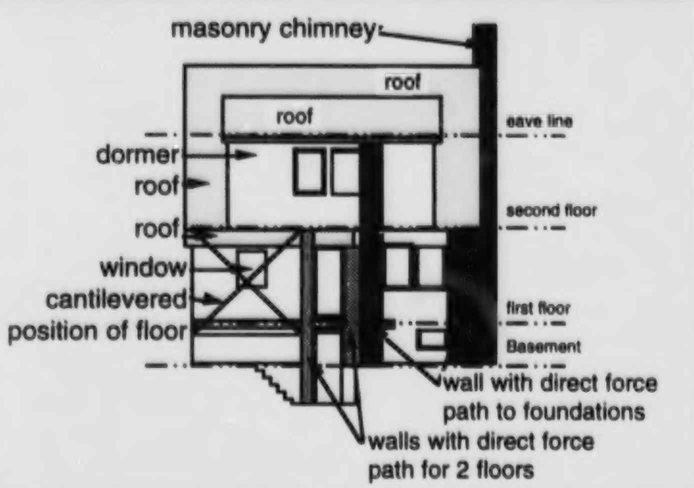


Figure 4C - 16:
South Elevation Showing Composite Force Paths



Item #

CONDITIONS TO CHECK

❑ **Laterally Braced Walls:**

Wood house framing techniques that have evolved have no bracing dedicated specifically to providing seismic resistance as part of their systems. The lateral rigidity of the house must be provided by other means. Braced walls have been developed to provide lateral support to the house and are an essential element used in seismic design. A 'braced wall' is a stiffened section of wall that helps keep the structure from racking when subjected to an earthquake or wind load.

There are several ways to strengthen a frame and to prevent racking. The common methods are:

(a)	Horizontal boarding	(1)
(b)	Horizontal boarding with diagonal bracing	(3)
	(b1) Using wooden diagonal bracing	(3)
	(b2) Using metal straps as diagonal bracing	(3)
(c)	Diagonal boarding	(6)
(d)	Plywood bracing (shear wall)	(8)

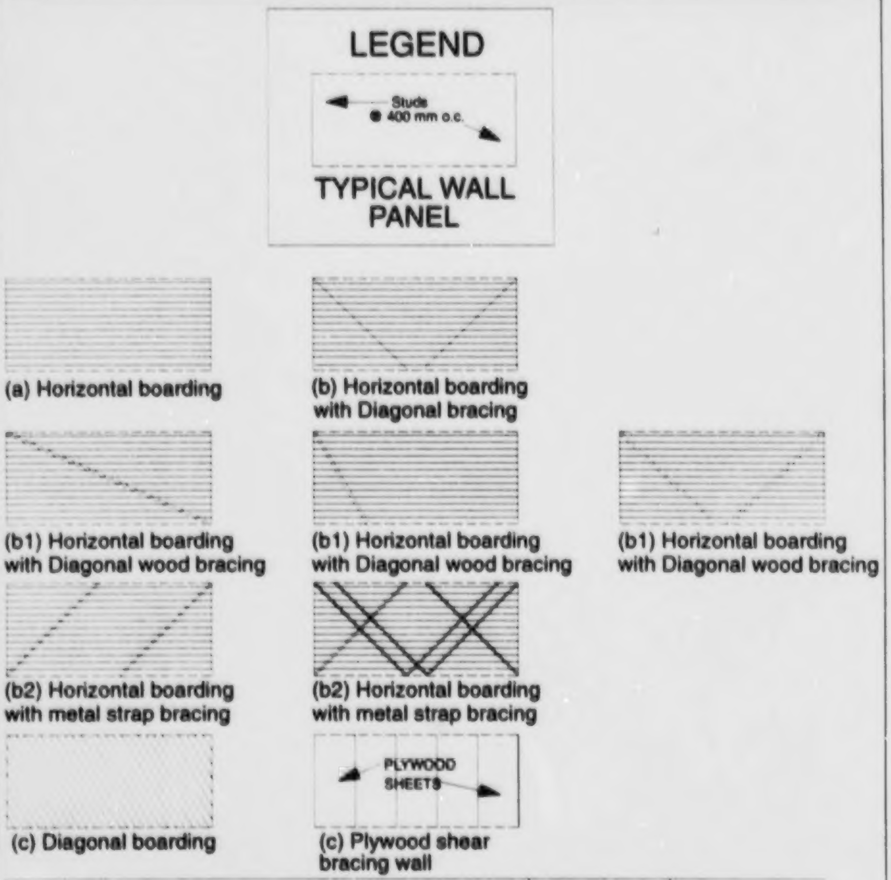
The numbers in the right column indicate the relative strength of each method. The horizontal boarded wall is assigned a strength number of 1. The numbers assigned to the other types of lateral bracing schemes represent the number of times stronger they are in comparison. Remember, as previously discussed, where doors and windows are placed in the wall, the strength declines. This is because openings effectively shorten the working length of the braced wall.[5]

Detailed information on the topic of laterally braced walls is provided by Albert Dietz in Chapter 5 of his book *Dwelling House Construction* and in a research paper by L.O. Anderson on "Guides to Improved Framed Walls for Houses." The detail given includes the relationship between types of boarding, nailing patterns, and framing systems and some information on the effect of various types of interior finishes. The following brief description of the various boarding and bracing techniques is based on their research.

RECOMMENDATIONS

❑ **Laterally Braced Walls:**

Figure 4C - 17:
Comparison of Laterally Braced Walls



PANEL TYPE	DESCRIPTION OF WALL	STIFFNESS FACTOR	STRENGTH FACTOR
(a)	200 (1 x 8") horizontal boarding, two nails @ each stud	1.0	1.0
(b1)	200 (1 x 8") horizontal boarding, two nails @ each stud with let-in 19 x 89 (1 x 4") wood braces	2.6	–
(b2)	- with 25 x 0.75 mm (1 x 0.03") steel straps	3.3	2.9
(c)	200 (1 x 8") diagonal boarding, two nails @ each stud	5.6	>6
(d)	16 mm (5/8") plywood, nailed 150 mm (6") o.c.	4.6	>8

Item #

CONDITIONS TO CHECK

(a) HORIZONTAL BOARDING - Relative Strength 1
Horizontal sheathing boards, when two nails are used in each board crossing each stud, can provide good resistance to racking when nailing has been carefully positioned and all members are in good condition.

(b) DIAGONAL BRACING - Relative Strength 3
Diagonal bracing stiffens the framing against deformations and also provides a more direct path for the transfer of the earthquake forces to the foundation. One common method is a continuous wooden member attached at an angle across the frame, and notched into the frame. Another method is the use of steel members that are attached at an angle across the frame in the form of an 'X'.

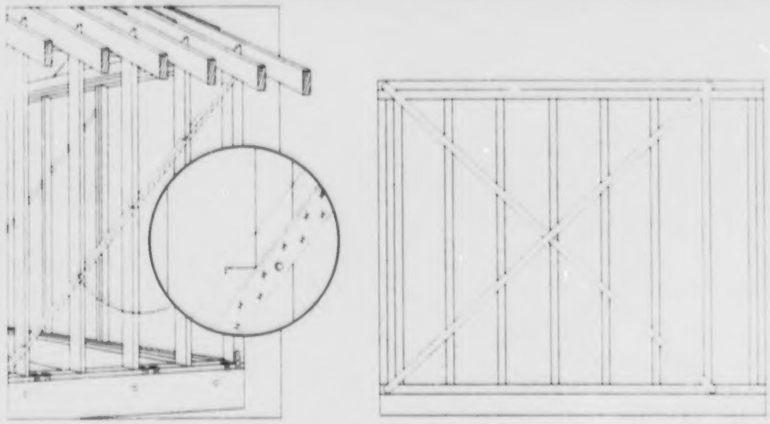
(b1) WOODEN DIAGONAL BRACING - Relative Strength 3
Diagonal bracing consists of 25 mm thick x 100 mm wide (1" x 4") boards let-in (notched) to the studs from the end to the wall, running from the sill plate to the top plate and back down again. Ideally, diagonal bracing should zigzag at about 60 to 45 degrees. Where openings for windows or doors interrupt the pattern, the angles are adjusted so the braces still run uninterrupted from sill to top plate. Correctly done and plentifully used, this kind of bracing adds a great deal of rigidity to the frame, similar to that provided by diagonal boarding.

(b2) METAL STRAP DIAGONAL BRACING - Relative Strength 3
There are two other stiffening systems that are similar to the wood let-in-brace: diagonal flat metal strapping and diagonal T-strapping. The flat metal strapping 75 mm (3 x 18 gauge) is good in tension, but has no strength in compression, thus it must be used corner-to-corner in an X pattern. The T-section is installed in the same diagonal pattern, but is installed by cutting a diagonal kerf 25 mm (1") deep before nailing the strap to each stud.[8]

(c) DIAGONAL BOARDING - Relative Strength 6
Sheathing boards are installed on the diagonal at 45 degrees to the studs and from the sill plate to the top plate at the roof. As in the horizontal boarding, two nails are used in each board where it crosses each stud. With diagonal boarding, racking stresses are transferred directly down the sheathing boards to the sill plate and then to the foundation. Diagonal boarding is therefore much stiffer and resistive than simple horizontal boarding or diagonal bracing.

RECOMMENDATIONS

Figure 4C - 18:
Perspective and Elevation of Metal Braced Wood Frame Walls



Item #

CONDITIONS TO CHECK

(d) PLYWOOD (SHEAR WALL) BRACING - Relative Strength 8

Plywood bracing is the strongest lateral bracing system. Like any other bracing system, plywood bracing will be effective only if the wood is of good quality and the nailing pattern is accurate. A variety of other panel products, such as oriented strand board (OSB) exist, which may be used instead of plywood.

When installing plywood braced walls, the plywood must be nailed to a fully-blocked nailing surface. There cannot be edges of the plywood that lack structural backing and the plywood must be nailed on all perimeters and to the intermediate studs.

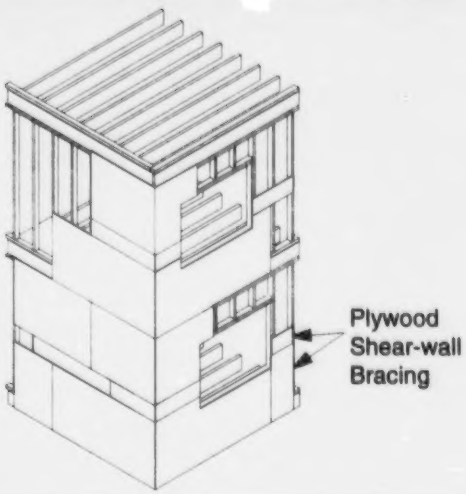
❑ **Location and Extent of Laterally Braced Walls:**

Laterally braced walls at the perimeter of the house should be located starting at the corners with a wall in each direction. They should be distributed equally along all the exterior walls of the house. Positioning walls in a symmetrical pattern on the perimeter minimizes the rotational effects of an earthquake. Braced walls should extend from the foundation continuously to the full height of the roof. Openings through these braced walls should be minimized. Where openings occur, reinforce the framing around them with steel straps. The extent of the walls that are needed depends on the height of the building.

Laterally braced walls that have a large height compared to width do not perform as well as those of standard proportions during an earthquake. Therefore, a series of tall, but narrow, braced walls will not provide the same resistance during a quake as a single wall covering the same total linear length of wall.

RECOMMENDATIONS

Figure 4C - 19:
Typical Plywood Bracing (Shear Wall) Shown in Platform Frame Wall Application



Because of the importance of plywood braced walls as a method of achieving seismic resistance in houses, Appendix C of this *Guide* provides additional details of plywood shear wall construction.

❑ **Location and Extent of Laterally Braced Walls:**

- The following are the rules of thumb indicating the percentage of perimeter walls that should be constructed when using plywood braced wall systems:

Table 4C - 1:
Minimum Percentage of Perimeter Walls to be Constructed as Plywood Braced Shear Walls

	Main & Cripple	Second	Third	Exterior Grade Plywood Thickness
One storey	20%	None	None	12 mm (1/2")
Two storey	25%	20%	None	16 mm (5/8")
Three storey	40%	25%	20%	19 mm (3/4")

A method of calculating the length of walls requiring bracing is shown in Appendix C, Technical Details. Both the table and the calculations are generic and based on simple rectangular floor plans, which, in fact, comprise the bulk of the existing Canadian housing stock. These sources should yield a general idea about the amount of bracing required. Consult a professional in order to make a determination of requirements for a particular house.

Refer to the case study in Appendix F for an example of the application of these and other design parameters to the existing house.

Item #

CONDITIONS TO CHECK

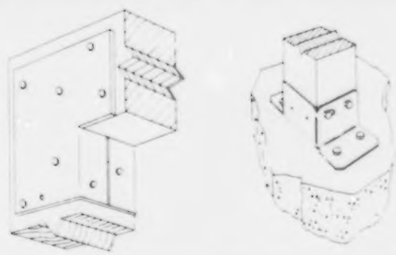
C5	**COLUMNS**
C5.1	❑ **Wood Columns (Post):** Columns are frequently used inside foundations for supporting the first floor above crawl spaces and basements. They are also commonly used to support simple exterior decks or to form carports that often have living areas above them. The post and beam system can also be used as the structural system for an entire house (See Chapter 4, Section C, page 100). At best, columns and their connections are a weak form of seismic resistance. Wood columns often fail because they have been weakened by decay, because they have been subjected to water at the base or head or because of insect damage. Another major point of structural weakness in earthquake resistance of columns is inadequate connections between columns and the sills, joists, beams or other horizontal structural members. These deficiencies are very common. Fortunately, there are several techniques to correct the conditions. Although inconvenient, it may be necessary to remove the finish materials on columns and adjacent surfaces to assess the conditions.

RECOMMENDATIONS

❑ **Wood Columns (Posts):**

- Check all columns to assess the condition of the structure. If a column is found to be damaged, the cause of the condition must be determined and corrected before the column is replaced. All damaged wood in the zone should be removed. Remaining wood and replacement wood should be preservative treated. Further information on preservative treatment is located in Chapter 4, Section C, page 129.
- Assess the condition and adequacy of connections between columns and supporting structures. Install pre-engineered steel framing and anchoring devices to provide strength for vital connections between column head and base, and the adjacent structure. This necessitates the removal of all finish materials from within the area where the connectors are used. The steel devices must connect directly from one structural element to another with no extraneous materials within the connections.

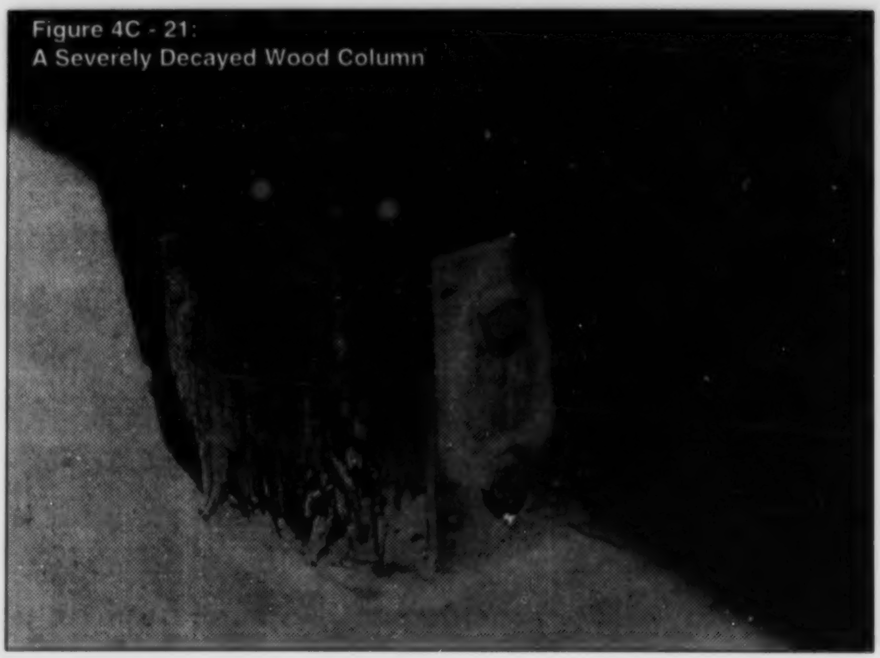
Figure 4C - 20:
Sample Column Connections at Cap and Base



- Refer to the discussion on connections in Chapter 4, Section C, page 126 for details regarding improving column connections to adjacent structure.

Item #

CONDITIONS TO CHECK

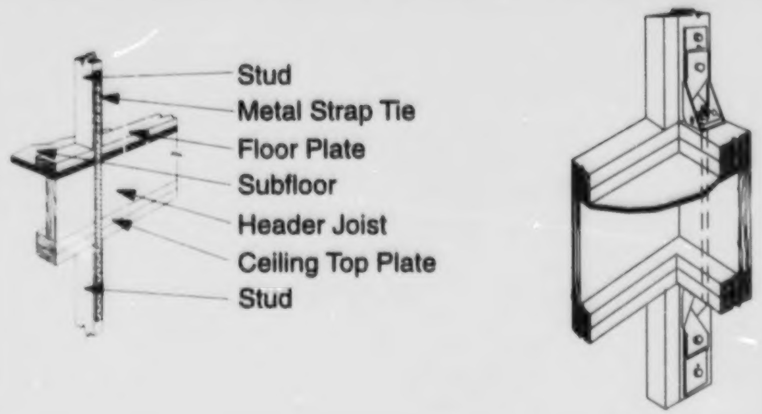
C6	**CORNERS**
C6.1	❑ **Corner Framing:** Under earthquake loads, corners of houses are subjected to tremendous forces, both vertically and horizontally. Corners must work to restrain and transfer the dynamic loads of the roof, the walls, and the floors to the foundation. The more load supported by the corner, the more important it is; thus a cripple wall corner is structurally more significant than one on the third floor. To resist lateral loads, corners should have braced walls, or a significant braced wall length near them. The standard framing technique for tying corners in wood structures is the use of double top plates connected, by nailing, to the studs or posts that form the end of the joining walls. The end wall studs are nailed together vertically in the corner, forming a built-up post. (Refer to Figure 4C-11 on page 101 for an illustration of typical platform frame corner construction.) The strength of corners provided by the nails at the top and bottom plates, together with those used to nail the studs to each other, is often inadequate to resist the quake-induced loads. Additional anchorage, tension and shear ties should be installed. Where corners are constructed of slender, unbraced columns with glass each side, or the even less stable configuration of glass right to the corner with no structural support, the condition must be upgraded. If the house structure were to fail during an earthquake, it will certainly fail at the unbraced corner. Refer to Chapter 4, Section B, page 78, for additional information.  Figure 4C - 21: A Severely Decayed Wood Column

RECOMMENDATIONS

- **Corner Framing:**
  If walls are of limited length, or absent from corners, consult a structural engineer for analysis and upgrade advice. Upgrade walls at corners to provide lateral bracing (previously discussed in this section, see Chapter 4, Section C, page 108) and install ties at each corner of each floor to connect the wall and floor systems.

  Where exterior finishes are not being completely removed, ties may be fastened from the outside by selectively removing finishes, exposing the underlying sheathing and corner framing structure. Ties may be fastened after the sheathing nailing is increased to the levels recommended in this *Guide*. When ties are in place, they may be covered by new finishes, decorative corner trim, or by repairing the original finish. Where interiors are being renovated and finishes are removed, steel hold-downs can be installed near corners from the interior.

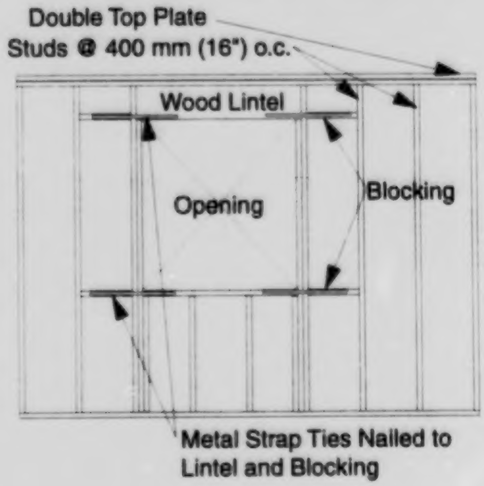
Figure 4C - 22:
Typical Floor-to-Floor Strap Tie and Floor-to-Floor Corner Hold-down Tie



Item #

CONDITIONS TO CHECK

Figure 4C - 23:
Framing Elevation Showing Reinforcing at Corner of Openings



Item #

CONDITIONS TO CHECK

C7	FLOOR AND ROOF DIAPHRAGMS

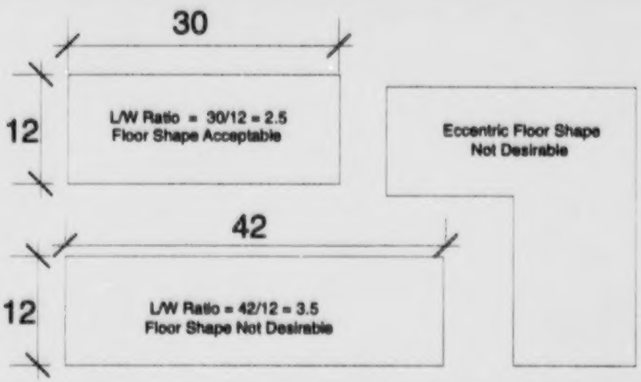
The forces of an earthquake are often successfully absorbed by the floor and roof diaphragms. When failures occur with these elements, they are usually associated with either the connections with the walls or foundations or where they have large openings, rather than in the diaphragms themselves.

There are a number of characteristics that make floor diaphragms more effective in transferring earthquake forces to the walls and foundation. However, only when the individual components (of sheathing, joists, rafters and trusses) and the blocking are thoroughly connected does the system act as a diaphragm.

Characteristics that make diaphragms effective include:

- Plywood floor sheathing is tongue and groove or the edges are supported by solid blocking. The use of glue and screws to connect the plywood sheathing to the supporting structure not only enhances the rigidity of the diaphragm but also minimizes floor deflection and squeaking.
- Blocking is installed between the joist at all sill plates and along their spans. Joists that lack blocking are subject to tipping, which can lead to collapse during a strong earthquake.[7] This blocking is often missing, therefore its presence should be verified. One way is to observe the diaphragms where they are exposed, such as in a basement or crawl space. If blocking is not present, it is probably not installed elsewhere in the house structure.
- The floor shape is simple and relatively symmetrical with a length to width ratio of less than 3:1.

Figure 4C - 24:
Floor Shape Illustration of Length-to-Width (l/w) Ratios and Eccentric Floor Plans



- Where the diaphragm plane is interrupted, such as for a sunken living room or in a split level floor plan or a change in roof levels, an interior braced wall and supporting foundation should be installed at the change in level. Unfortunately, this supporting wall is seldom constructed as a braced wall.
- Minimize the number and size of openings along the edges of the diaphragm. Corners are especially sensitive. Large openings such as for stairs, with a length of more than half the diaphragm, should have an additional shear wall and supporting foundation installed on one side of the opening.

RECOMMENDATIONS

- Where access is available, connections between the diaphragm and the supporting structure should be strengthened. Blocking should be positioned along the length of the joist at a maximum of 2.4 m (8 ft) intervals.

- To provide a positive floor diaphragm to top plate connection, install a steel angle connector on the top of the wall plate and fasten to the rim joist in each bay. Use another angle connector vertically to connect the joist end and the rim joist.

Figure 4C - 25:
Connecting Floor Diaphragms to Walls

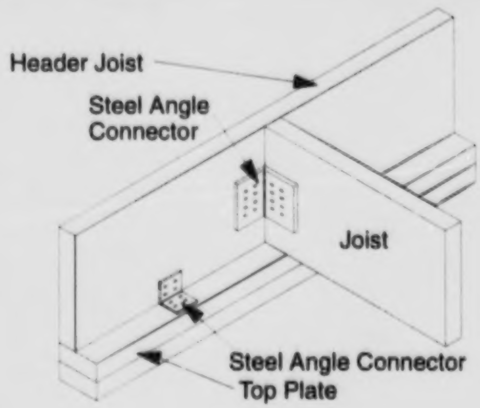


Figure 4C - 26:
Metal Angles Connecting Foundation to Sill Plate, Sill Plate to Joist Header and Subfloor Above

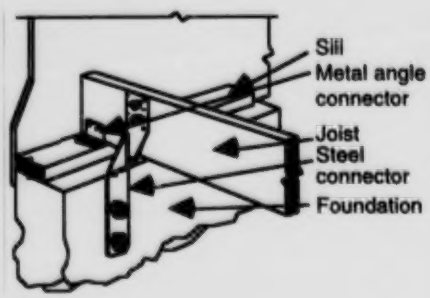
Item #

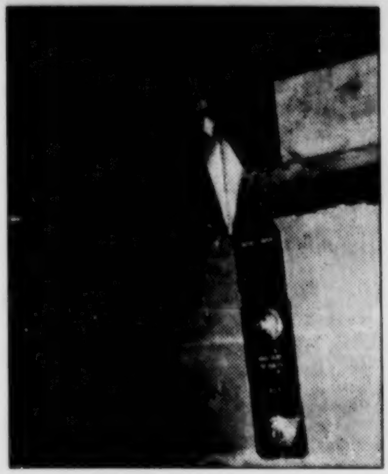
CONDITIONS TO CHECK

To effectively transfer seismic forces to the house structure as a whole, there must be a strong structural connection between the diaphragms and supporting walls. A common condition where diaphragm connections fail is where a wood ledger has been used. The balloon frame system makes extensive use of ledgers, or ribbons as they are also known. Ledgers are sometimes used in other types of frames to support a diaphragm on the inside face of foundations or on structural wood walls. The use of laterally braced walls and steel connectors are techniques that effectively provide continuity between the diaphragm and the supporting structure, allowing the frame of the entire house to work together to resist earthquake forces.

RECOMMENDATIONS

Figure 4C - 27:
Connecting Floor Diaphragms to Foundations





- Connections between the diaphragm and the supporting structure are subjected to the greatest forces at the corners of the house. The use of framing anchors and framing straps ties the floors to the walls, maintaining a continuous force path in the frame and strengthens higher stress areas. Another critical zone is where diaphragm and ledger connections exist. Installation of engineered steel connections between all members of the structural system at corners and ledgers is highly recommended, with anchors and metal straps to tie them to the supporting walls.

Figure 4C - 28:
Connecting Diaphragms to Supporting Structures

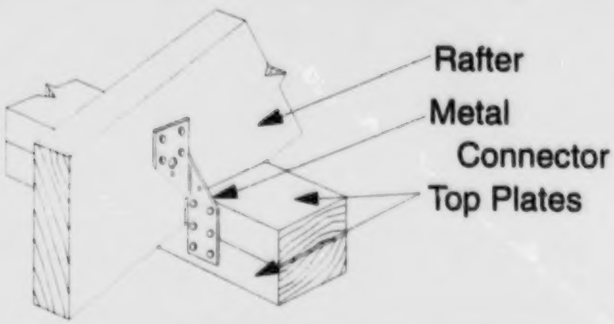
Roof to frame below   Floor to frame above and below   Floor to foundation

Item #	CONDITIONS TO CHECK
C7.2	**Roof:** Failures of roof diaphragms often occur when they support heavy loads. The loads can be a function of the roof materials used - materials such as clay tile, slate or concrete roof tile. For example, a clay tile roof on a 150 m^2 (1600 ft^2) house weighs about 7800 kg (17,000 lb) more than it would if roofed with asphalt shingles. Temporary loads can be imposed by nature in the form of snow, ice or water. The fact that snow loads tend to build up on one area of the roof, rather than being evenly distributed, compounds the seismic risk. The taller the house, the greater the hazard the roof load imposes. This is because the ground motion is amplified by the height of the building and weight of the roof, causing much larger forces on the supporting structures below. Tying the roof diaphragm to the top wall plate stabilizes the house's structural system. Sloping roofs associated with flat ceilings form a triangulated structural system and are usually very seismically resistant. But, whether flat or sloped, proper framing techniques and connections to the top of the walls that support them are essential. Roof diaphragms are often interrupted by architectural features, such as large skylights, or they are built on several different levels. The size and location of these features can be critical to the performance of the diaphragm during an earthquake. Spaced boards used under wood shakes and shingles or under clay and concrete roof tiles add little to the roof structure's earthquake resistance. Solid sheathing products, such as plywood, generally provide adequate seismic resistance so long as they are structurally nailed to the supporting structure and are in good condition. Sheathing products are usually of sufficient thickness and inherent strength because of the characteristic need to support roof materials and snow and wind loads.

RECOMMENDATIONS

- To provide positive roof diaphragm to top plate connections, install a metal connector from roof members across both top plates. This can be done from above when roof or diaphragm replacement occurs or from below through the attic space. Openings, such as those for chimneys and skylights, should be reinforced with solid blocking and the use of engineered steel connectors.

Figure 4C - 29:
Connecting Diaphragms to Supporting Structures



- Use any opportunity associated with roof maintenance or renovations to substitute structural panel products as sheathing replacement for spaced boards in the structural system. When roofing with wood shakes or shingles, use a ventilation mat above the sheathing to provide ventilation for the roofing material. The panel products must be nailed to the supporting roof structure as recommended for laterally braced plywood walls (for nailing pattern refer to Appendix C, Technical Details).
- Where a partial roof upgrade is undertaken, enlarge the replaced areas so that they extend to the edges of the roof diaphragm. Tie the upgraded roof diaphragm to the supporting walls or gables. Upgrade the gable walls to act as laterally braced walls.

Item #

CONDITIONS TO CHECK

C8	**STRUCTURAL CONNECTIONS**

❑ **Seismic Connections:**

The structural materials from which the house is built and the connections between them determine the resistance of the building to earthquake forces. Coupled with knowledgeable seismic design and attention to details during construction, wood houses can be made very resistant to earthquake damage.

Steel connections provide a relatively low cost, relatively simple method to overcome common deficiencies found in wood framing systems. These devices should be used to anchor the wood frame to foundations, to brace walls and to tie the variety of wood components together. The objective is to provide a continuous path from the roof structure to the foundation, which will successful transfer the forces imposed by earthquakes. Use of steel connectors will increase the strength and continuity of the structure to enable the house to respond as a unit.

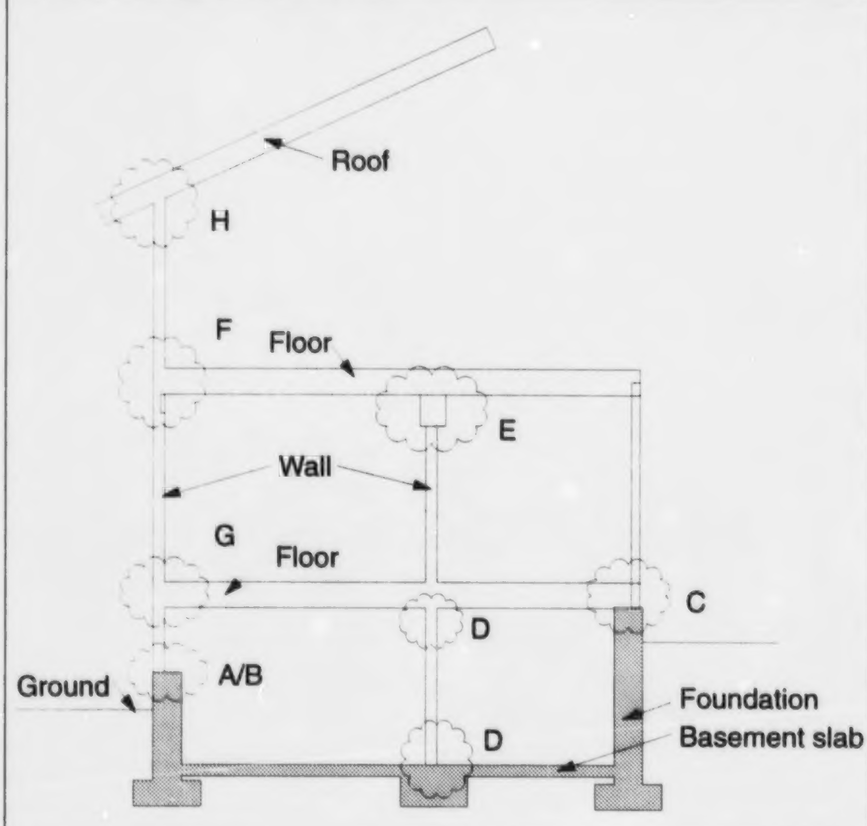
RECOMMENDATIONS

❑ **Seismic Connections:**

The following are common conditions where connections are critical. (Drawings that relate technical details of the connectors to specific conditions are located in Appendix C.)

- Foundation connection with the sill plate (A),
- Sill plate connection to cripple or stud wall (B),
- Sill plate connection to floor framing (C),
- Column connections at base and head (D),
- Joist and beam connections (E),
- Ledger to wall connection (F),
- Floor to wall connection (G),
- Roof to wall connection (H).

Figure 4C - 30:
Seismic Connections



CONDITIONS TO CHECK

Item #

C8.1

❑ **Sill Plate:**

Older buildings are likely to have some damage to the foundation and the wood structures near foundations due to the ravages of time, but damage is also commonly found in houses that are just a few years old. Decay or insect damage in the sill plates and in other wood associated with the foundation is due to its proximity to the ground and exposure to water. A condition that frequently leads to this damage is dirt above the top of the concrete foundation wall, which allows both moisture and insect penetration into the wood frame. Any existing damage must be repaired. Like a cancer, if left unattended it will spread and weaken the entire structure. Under the stresses of an earthquake, damaged connections between the wood structure and the foundation will fail. Repairs to this area of the house are often difficult, hence expensive.

Confirm that the sill plate is at least 38 mm (1.5") thick. Check that the wood is of good quality, that it is without major checks, cracks, splits or knots, and that it is free of decay or insect damage. There are also some houses built without sill plates, where the joists rest directly on the foundation. The wooden sill plate is an important element in the seismic connection between the house frame and the foundation.

It is very important to identify the source(s) of any damage to sill plates, and to repair the damage and the root problem, or there is no point in making the other sill plate repairs.

Figure 4C - 31:
Typical Sill Plate and Wood Studs at Foundation Wall

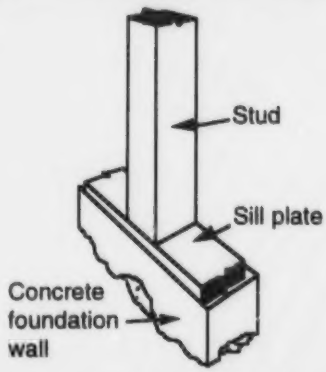
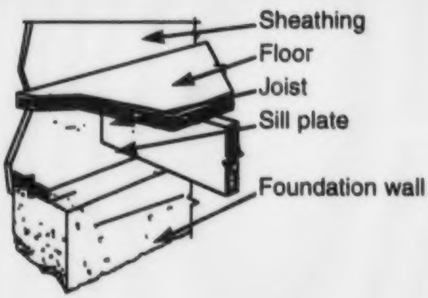


Figure 4C - 32:
Typical Floor Diaphragm on Sill Plate at Foundation



RECOMMENDATIONS

- **Sill Plate:**

- Look for a dry, spongy and crumbling condition in the sill plate and adjacent wood members. Test the wood by probing with a pointed instrument, like an ice pick. If the probe easily penetrates the wood, it probably has decay. Try to determine the causes of the decay, such as contact with the earth or water.

- Where damage in existing sill plates has been found, the affected area should be carefully removed. Build a temporary structure to support the wall and joists above the sills being replaced. Cut the sill plate so that the remainder has squared-off ends and no evidence of damage remains. Examine the bottom ends of studs exposed when the sill plate is removed, and replace any that are damaged.

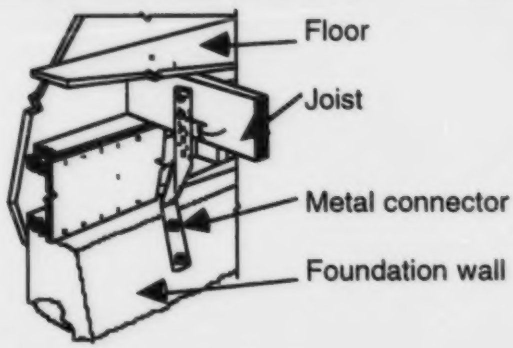
- Prior to adding new material (sill plate, studs, sheathing), saturate the exposed ends of the existing sill plate and studs with a preservative solution such as borax or copper napthanate to reduce decay and the number of insects entering the ends of the wood members.

- Replace damaged sill plate sections with minimum 38 x 140 mm (2" x 6") wood treated copper chromium arsenate (CCA), suitable for ground contact use (according to the standard CAN/CSA - O80 - M89,"Wood Preservation", to 6.4 kg/m^3). Saturate all the cuts made in the wood with the same solution with which they were commercially treated. Other damaged members such as studs and joists should be replaced with preservative-treated lumber of the original dimensions.

- In some municipalities in seismic zones, a common practice that continues today is to directly fasten floor joists to the concrete foundation or to a wood member such as one that is 38 x 89 mm (2" x 4") embedded into the concrete foundation. This is not and never has been a recommended practice. However, if a home has this condition, it becomes necessary to:
  (a) ensure the floor diaphragm above the basement level is well attached to the floor joists, using metal connectors where possible; and
  (b) attach the floor joists of the lowest floor directly to the concrete foundation wall, using metal connectors.

  The quantity and disposition of the various connectors will have to be determined on a case-by-case basis.

Figure 4C - 33:
Foundation-to-Joist Anchor



Item #	CONDITIONS TO CHECK
C8.2	❑ **Sill Plate Connections to the Foundation:** A common cause of severe damage to houses results from inadequate connections between the foundation and the wood structure. Many houses, including those under construction in areas of Canada with high seismic hazards, have wooden sill plates resting on the top of foundation walls without sufficient (or any) connection. The weight of the house often provides the only resistance to seismic movement. It is imperative that the connection between the framing and the foundation be secured at regular intervals. In newer houses, anchor bolts are typically present (but not always), but the connection often is not complete because nuts, with washers, have not been installed. The National Building Code of Canada states that: "Building frames shall be anchored to the foundation... by fastening the sill plate to the foundation with not less than 12.7 mm diameter anchor bolts spaced not more the 2.4 m centre to centre. The anchor bolts shall be fastened to the sill plate with nuts and washers and shall be embedded not less than 100 mm in the foundation..."[3] Check to see if the house is connected to the foundation. If not, it may slide off the foundation during an earthquake. Look for evidence of 12 mm (1/2") bolts going through the wood sill plate and into the foundation. A preliminary inspection can sometimes be done from the exterior, by removing ventilation screens, and more thoroughly from inside the house.

RECOMMENDATIONS

❑ **Sill Plate Connections to the Foundation:**

- To check the connections, go into the basement or in the crawl space under the house and inspect the foundation. See if the sill plate is connected to the foundation with steel nuts and washers threaded on anchor bolts and note the spacing and location of the connections. In seismic areas, the spacing should not exceed 2 m intervals for single-storey houses and 1.2 m for more than one-storey structures.
- What if the house is built on a concrete slab on grade, that is, what if there is no crawl space? To check the condition of the sill plate and to confirm the presence and spacing of anchors, there must be access through either the inside or outside of the walls. The inspection should begin at building corners and other areas along the walls where damage is evident, places where renovations or repairs are going to be made. However, even spotting anchors along one stretch of foundation will not guarantee that other areas are the same. Remember to carefully check the condition of the sill plate. In this form of construction they are often deteriorated. If additional anchor bolts need to be installed, either expansion or epoxy systems can be used.
- For high risk seismic zones, additional requirements should include spacing between connections of not more than 1.2 m (4 ft), they should be located within 200 mm (8") of each end of each piece of sill plate, including all building corners, and with a minimum of two connections for each piece of sill plate.

Item #

CONDITIONS TO CHECK

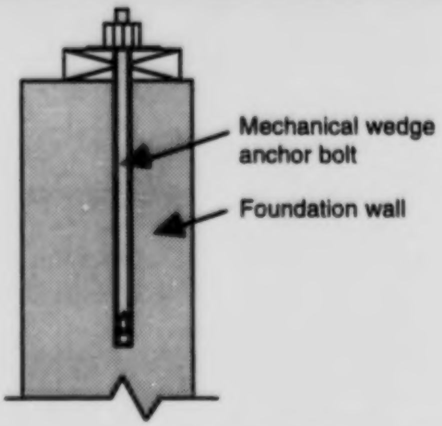
132	❑ **Anchor Bolts and Other Steel Connectors:** An anchor bolting system, approximating that which could have been installed when the concrete foundation was built, can be installed using upgrading techniques. One type of anchor bolt connection is called an expansion bolt and another is an epoxy set system.

RECOMMENDATIONS

❑ **Anchor Bolts and Other Steel Connectors:**

- An anchor bolting system, approximating that which should have been originally provided, can be installed using expansion bolts. The expansion bolt system works by expanding a wedge against the sides of its hole in the foundation. When correctly installed, it will resist thousands of kilograms of force. For the upgrade of sill plate connections, use 12.7 mm (1/2") diameter or larger expansion bolts. The bolts should penetrate the foundation more than 125 mm (5"), so they need to be at least 180 mm (7") to accommodate the thickness of the sill plate and provide threads for the washer and nut. Use a wood bit to drill through the wood sill plate; then use a hammer drill with a carbide tipped bit to drill a hole through the top of the foundation wall.

Figure 4C - 34.
Installation of Expansion Bolt in Existing Foundation Wall



Item #

CONDITIONS TO CHECK

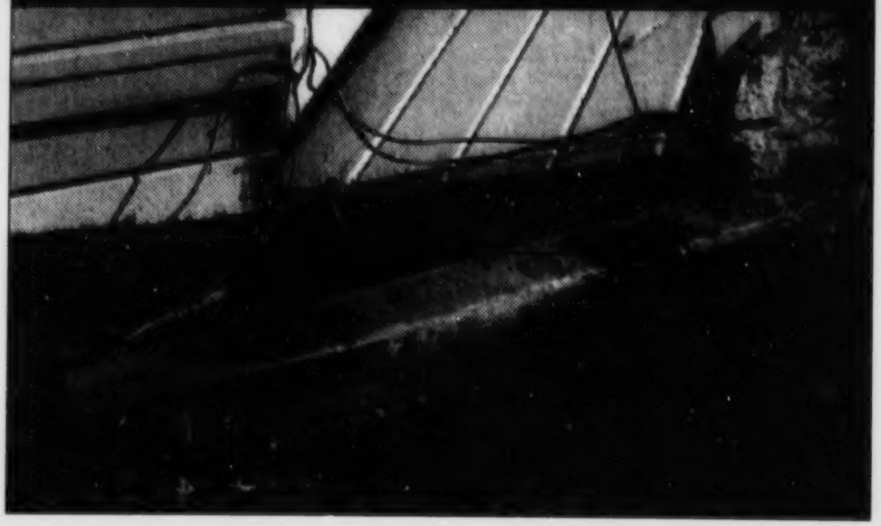


Figure 4C - 35:
Poor Connections Between Sill Plate and Frame Caused Slippage

The standard method of installing additional anchor bolting is to drill vertically through the sill plate into the foundation; however, sometimes this is not possible. If working space above the sill plates or other conditions make the use of anchor bolts difficult, use other techniques that have been developed for attaching the sill plate to the foundation.

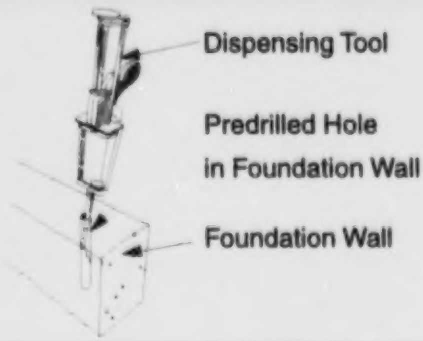
Check sill plate and determine if the minimum connection intervals to the foundation exist. There should be:

- Two connections for each piece of sill plate.
- Connectors within 200 mm (8") of each end of each piece of sill plate.
- Connectors within 200 mm (8") of ends of existing sill plate sections where they meet new section.
- Along the length, intervals of 1.2 m (4 ft) for houses in high risk seismic zones (2 m [6 ft] in other zones).

RECOMMENDATIONS

- A good alternative system is the epoxy set anchor bolts. The epoxy set is the strongest type of upgrade anchor that can be used, but is more expensive and requires more care in preparation and installation. This system utilizes a two-part epoxy mix that is placed into a hole that is 1 to 2 mm larger than the threaded rod that is placed in it. The advantage of the epoxy anchor is that it adheres to all of the surface area of both the rod and the hole. It does not stress the surrounding foundation materials. It differs from the expansion bolt type anchor that depends mostly on the tip to keep the bolt from pulling out. This is an important consideration when spalling is of concern (due to a poor quality foundation) or when there is a need to place a bolt near a corner or an edge. The epoxy also protects the embedded portion of the anchor from moisture and corrosion.[9]

Figure 4C - 36:
Installation of Epoxy Set Anchor Bolt in Existing Foundation Wall



- An alternative foundation connector is the bent steel plate (in the shape of an angle iron) where the top leg bears on and is nailed to the top of the sill plate and the leg is bolted at least 150 mm (6") below the top of the foundation. The configuration eliminates the need for vertical drilling but provides good resistance to horizontal and vertical movement.

Figure 4C - 37:
Alternative Steel Foundation Connector Used Due to Limited Installation Headroom

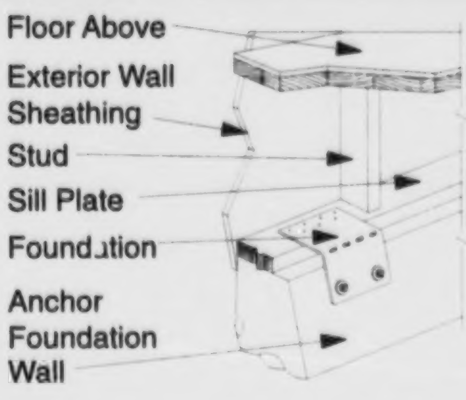
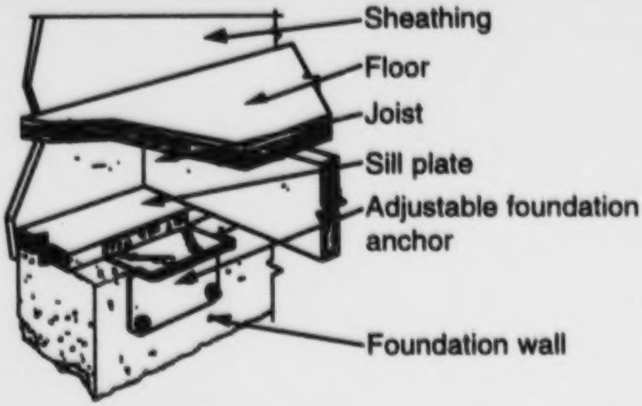


Figure 4C - 38:
A Foundation Anchor for Low Headroom

RECOMMENDATIONS

- The attachment can be accomplished by installing engineered slip-connection steel plates along the side of the sill plate and the foundation, which permits all the connections to be done horizontally. Holes in the two plates are pre-drilled for the lag bolts into the sill plate and anchor bolts into the foundation. The connection is centred on the side of the sill plate and at least 150 mm (6") below the top of the foundation.

Figure 4C - 39.
Alternative Engineered Steel Connector Used to Anchor Sill Plate to Foundation Wall



Item #	CONDITIONS TO CHECK
C8.3	❑ **Sill Plate Connections to the Wood Frame:** Additional wood blocking can be used to tie wall framing members to the sill plate. Framing anchors can be used to connect wall framing or floor framing to sill plates. Hold-downs that bolt through the sill plate into the foundation and are fastened to the wall frame members are often placed at building corners.

RECOMMENDATIONS

❑ **Sill Plate Connections to the Wood Frame:**

Strengthen connections between the sill plate and the wood framing it supports. A number of techniques can be used individually or in combination, depending on the configuration of the structure.

- Where the sill plate supports stud framing, add 38 x 89 mm (2" x 4") blocking on top of the sill and between every other stud. Connect the studs to the blocks by driving two nails through the side of the stud into the end of the new blocks. Then connect the new block to the existing sill using three nails. When the connection of the studs to the new blocks is completed, install additional 38 x 89 mm blocks in the adjoining spaces and connect them to the sill plate using three nails. Dimensions between studs should be measured and the blocks cut to fit the existing conditions. Use 89 mm (3-1/2") common nails for the connections. An additional benefit of installing blocking is that it provides a surface even with the face of the studs for the connection of lateral bracing.

Figure 4C - 40:
Additional 38 x 89 Blocking Used to Reinforce Connection, Between Sill and Stud Framing

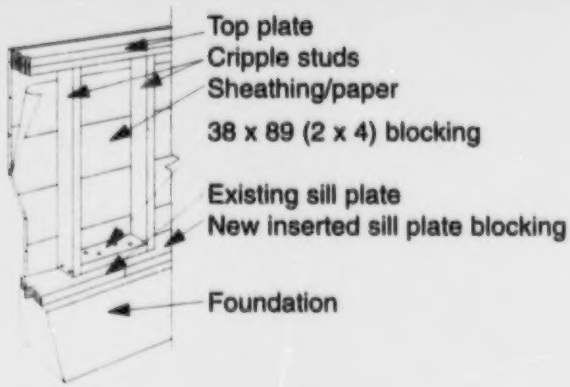
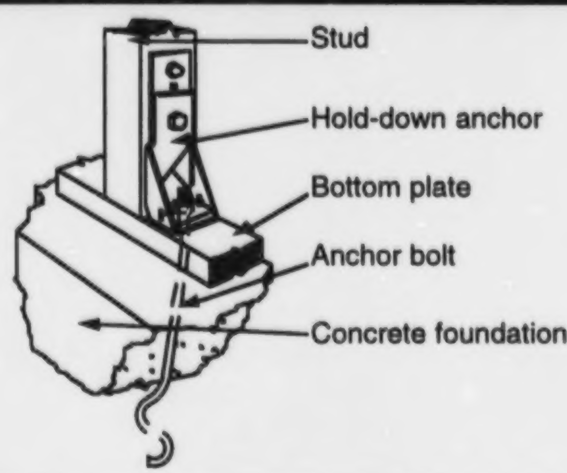


Figure - 4C - 41:
Hold-down Anchor Through Bottom Plate to Concrete Foundation

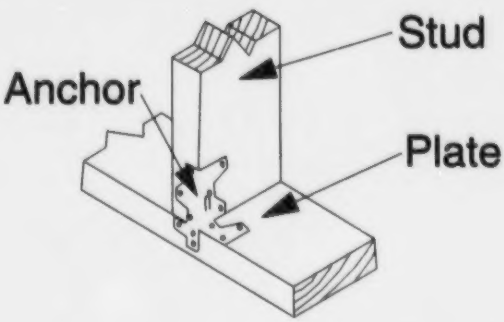


Item #	CONDITIONS TO CHECK

RECOMMENDATIONS

- If nailing is awkward or additional strength is desired, use engineered steel connectors to attach the stud to the sill plate. These connectors resist forces in both horizontal and vertical directions. They can be installed on both the inside and outside face of studs if additional strength is required. Steel connectors can be used in conjunction with the wood blocking as explained above.

Figure 4C - 42:
Strengthening Stud-to-Plate Connections



Item #

CONDITIONS TO CHECK

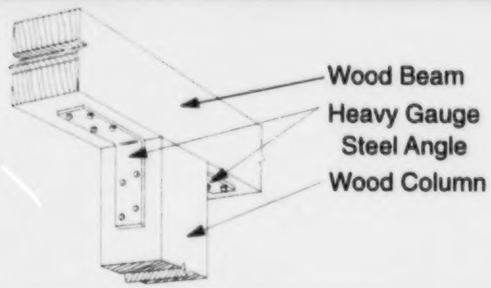
C8.4

❑ **Column Connections:**

Column connections to the structure at both the base and the head are major points of seismic weakness. The use of pre-engineered steel framing and anchoring devices can provide significant strength for these vital connections.

Columns are inferior as seismically resistant structural elements, as they concentrate applied loads on a single point. Unless well braced and connected, they are highly prone to failure in an earthquake. Wherever possible, it is desirable to stabilize columns with cross bracing or laterally braced walls.

Figure 4C - 43:
Heavy Gauge Steel Angles Acting as Connector Between Wood Column and Beam



RECOMMENDATIONS

❑ **Column Connections:**

- Where post caps are already in place, check that they are fabricated from steel of at least 12 gauge (2.7 mm -1/64") thick material. Each face of the beam and the column should be connected with at least four nails of 3.8 x 76 mm (3"- refer to Table C-1 in Appendix C for information on nail sizes). If existing connections are not substantially as recommended, consult a seismic design professional for recommendations.

Figure 4C - 44:
Steel Connector Between Wood Column and Beam

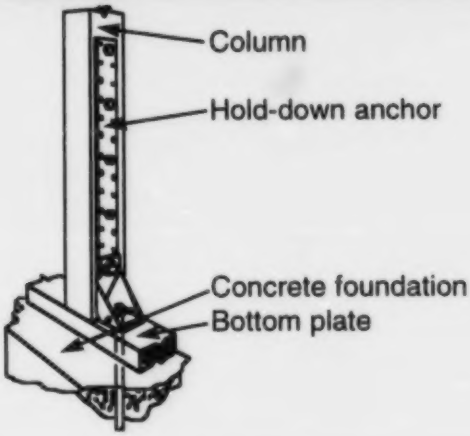
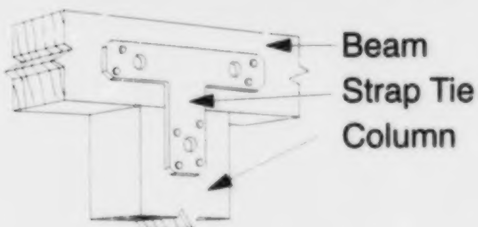
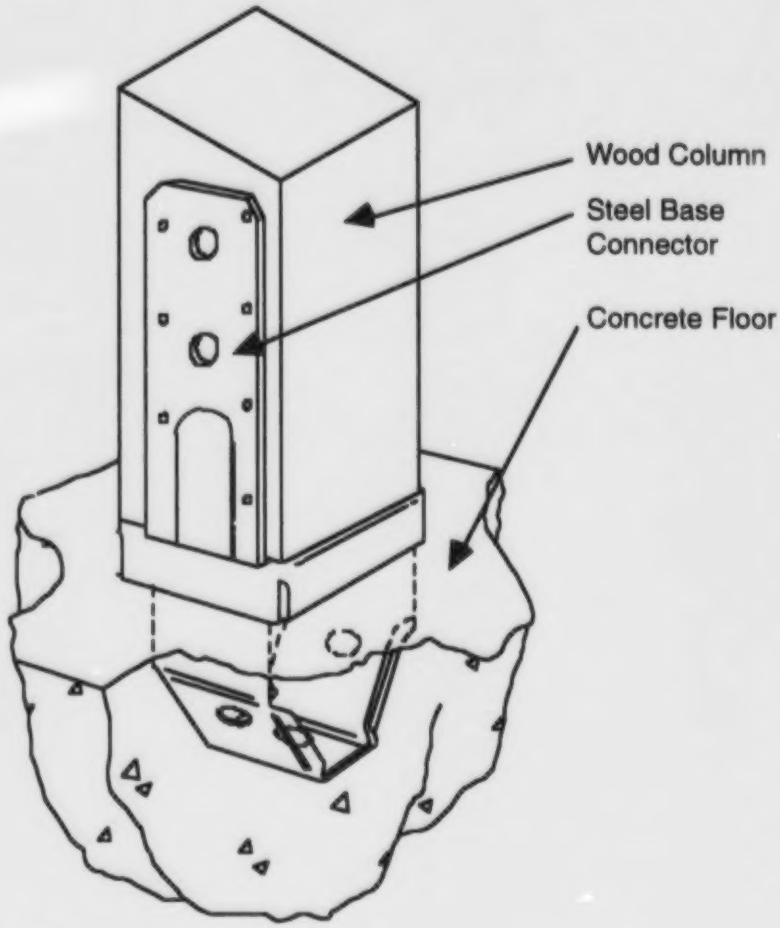


Figure 4C - 45:
Steel Strap Tie Alternative for Post Cap Upgrade



Item #	CONDITIONS TO CHECK

Figure 4C - 46:
One Method of Fastening Post Base to Concrete or Wood Floor Structure



Item #	CONDITIONS TO CHECK
C8.5	❑ **Joist and Beam Connections:** Until the mid-70s, wood-frame house structures were fastened together almost exclusively with nails. Nails used in framing each have a lateral resistance to shear forces ranging from 35 to 60 kg (80-130 lb).[10] A typical joist end nailed to a beam with three nails might fail under a load exceeding 180 kg (400 lb), substantially less than the forces that often attend an earthquake. Steel joist and beam hangars are designed to achieve specific connection strengths and for ease of installation. A typical engineered joist hangar (18 gauge) will easily carry loads at least twice as great as traditional nails can. An example of a built-up beam consisting of three 38 x 235 mm (2" x 10") joists, end nailed into a wood header, can be expected to have a resistance to shear forces of 540 kg (1200 lb). An engineered light gauge nailed beam hangar will provide a shear strength of at least 1400 kg (3100 lb), or more than 2 1/2 times.[11]

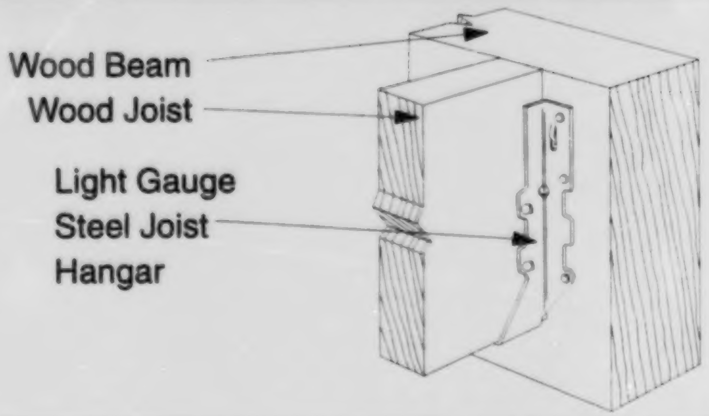
RECOMMENDATIONS

❑ **Joist and Beam Connections:**

- Steel joist and beam connectors are easy to install, as they do not involve disturbing existing nailed connections. They also provide consistent and known structural performance. They are designed for specific structural conditions, so care should be taken to use the appropriate product. To achieve the desired performance, they must be selected and installed based on factors such as dimensions and species of wood being jointed, direction and magnitude of forces acting on the connection, and type and number and sizes of fasteners necessary.

- In adding hangars, remember that, because of their thickness, they protrude slightly below the bottom of the joist or beam being supported and they project slightly from the face of the companion member. This may require placing a shallow recess in the members where the connector rests so the finishes that are to be applied over the hangar are not affected.

Figure 4C - 47:
Typical Light Gauge Steel Joist Hangar



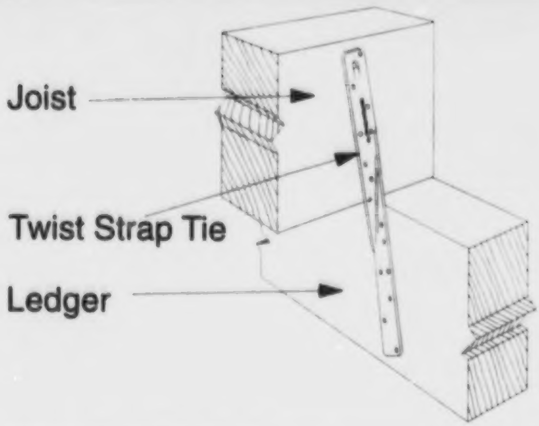
Item #	CONDITIONS TO CHECK
C8.6	❑ **Ledger Connections:** A condition where connections frequently fail is where a wood ledger has been used to support a diaphragm. The ledger is a supporting wood member that is attached to a foundation or structural wood wall. Typically, the floor diaphragm system rests on and is nailed to the ledger. The ledger itself can be attached to the structure using a variety of methods. Both diaphragm-to-ledger and ledger-to-structure connections are frequently insufficient to resist strong earthquakes.

RECOMMENDATIONS

❑ **Ledger Connections:**

- Where diaphragm and ledger connections exist, install engineered steel anchors and metal straps to tie them to the supporting walls. The steel connectors keep the diaphragm from falling off the ledger or the ledger from pulling out of the wall or foundation. As an additional benefit, the diaphragm also adds considerable strength to the supporting walls and foundations by tying the walls together, much like the footings do at the base of the house.

Figure 4C - 48:
Strap Installation to Hold Joist onto Ledger

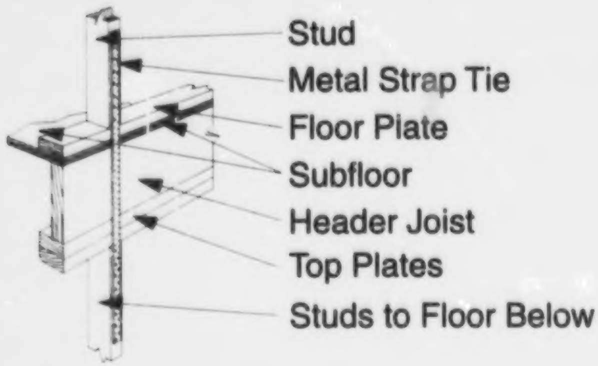


Item #	CONDITIONS TO CHECK
C8.7	❑ **Floor Diaphragm and Wall Connections:** A disadvantage of the platform framing technique that has been almost universally used in house construction for the past 40 years is that the walls of each floor are built independently of those below and only connected to the structure below by nailing. This often results in a discontinuity of the path connecting seismic forces to the ground, resulting in damage and failure. By comparison, earlier framing systems such as balloon and braced frames involved erecting studs to the full height of the structure. While there are other disadvantages to those framing methods, it would be advantageous for platform framing to incorporate methods that achieve similar continuous transfers of forces. Steel strap ties and hold-down connectors are the most efficient methods of achieving this transfer. To maintain the continuous force path for transferring seismic forces, the braced walls should be connected to both the floor diaphragms and the foundations. The connectors should transfer uplift forces between the wall and floor systems.

RECOMMENDATIONS

- **Floor Diaphragm and Wall Connections:**
- Steel strap ties should be installed at a regular spacing on the face of the exterior framing. Ties are nailed to the lower end of the wall studs on the floor above, span across the floor diaphragm without nailing, and are nailed to the upper end of the wall studs below. The strap ties must extend along the face of the stud at a distance at least equal to the depth of the floor diaphragm and wall plates.

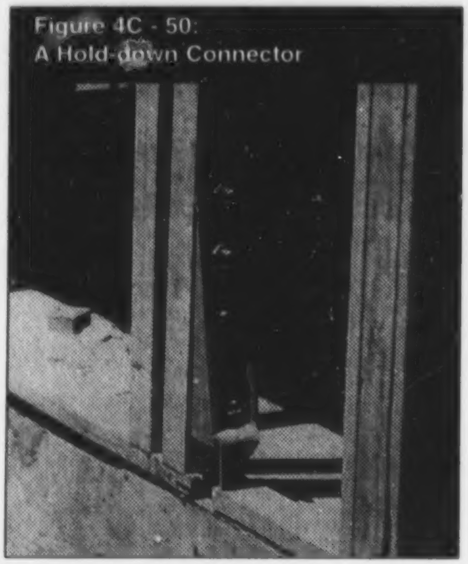
Figure 4C - 49:
Strap Tie at Floor Diaphragm



- Installing a hold-down connector involves exposing the stud work above and below the floor construction, either from the inside or outside. At each installation location, a vertical hole is drilled through the floor plate of the upper floor wall and the top plates of the wall below. Connectors are drilled and bolted onto wall studs above and below, then connected to a threaded rod that runs through the floor diaphragm. When bolts are tightened, the two wall structures become connected for seismic resistance.

Item #

CONDITIONS TO CHECK



C8.8 ❑ **Roof Diaphragm to Wall Connections:**

A strong connection between the roof diaphragm and the supporting walls ties the house together at the top, and is important in providing a continuous path for transferring seismic forces. Whether the roof is flat or sloped, roof connections to the top of the walls that support them should be reinforced with steel connectors. All types of roof structures, such as trusses, engineered joist and dimensioned lumber, can be connected using engineered steel connectors or roof ties designed to transfer forces both vertically and horizontally.

Openings in the roof diaphragm, such as those for chimneys or skylights, should be reinforced with solid blocking and the use of engineered steel connectors.

RECOMMENDATIONS

Figure 4C - 51:
Hold-down Connecting Upper and Lower Hold-down at Floor Plate

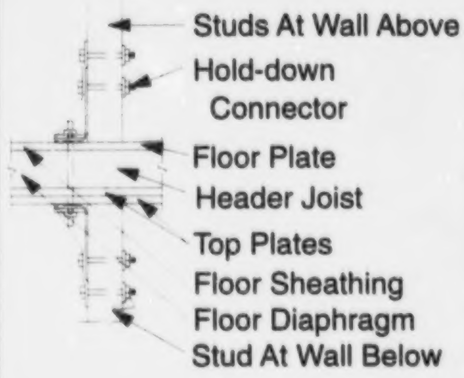
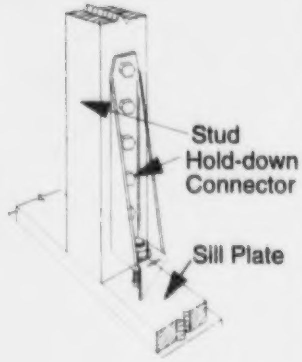
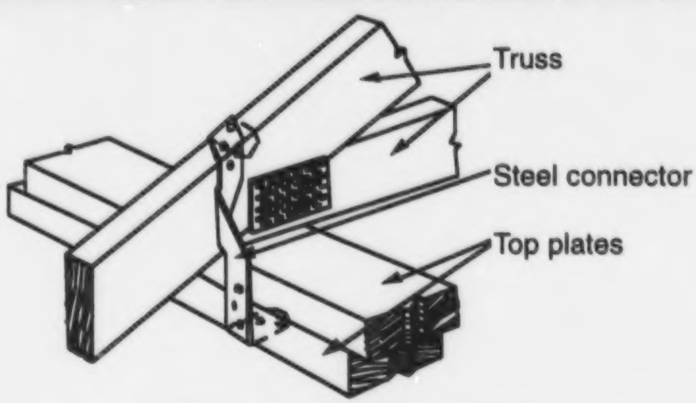


Figure 4C - 52:
Hold-down at Floor Plate



- ❑ **Roof Diaphragm To Wall Connections:**

Figure 4C - 53:
Roof Truss Structure Connected to Top Plates of Supporting Walls



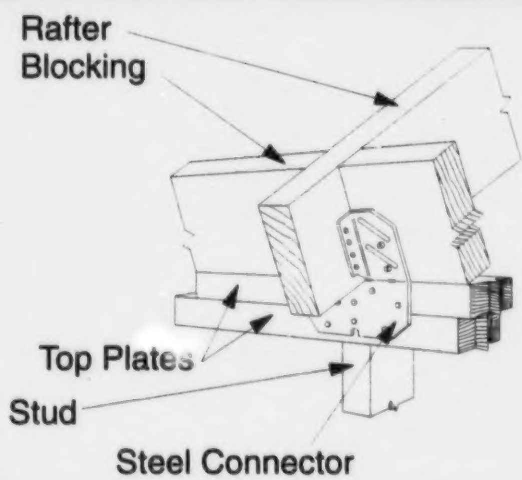
Item #

CONDITIONS TO CHECK

RECOMMENDATIONS

- The addition of continuous (freeze) blocking between the rafters (or trusses) and the connection of the blocking to the double top plates of the supporting wall will further increase the strength of the connections between the roof diaphragm and the wall. Freeze blocking must be done by providing the necessary cross ventilation of the insulated roof spaces.[12]

Figure 4C - 54:
Roof Diaphragm Connected to Freeze Blocking and Top Plates of Supporting Walls



- Connections between the roof diaphragm and the supporting structure are especially important with heavy roof systems or heavy loads such as snow. Fasten the roof diaphragm to the double wall plates below and the freeze blocks between the roof and ceiling framing in each bay using steel connectors. It is equally important that the framing supporting heavy roof loads also be strengthened all the way to the ground, so that the structure can resist the roof loads during an earthquake.

[1] Helfant, David Benaroya, (1989), *Earthquake Safe: A Hazard Reduction Manual for Homes*, Builders Booksource, 1817 Fourth Street, Berkeley, CA, p. 20.

[2] Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., p. 117.Helfant, p. 33.

[3] Helfant, p. 33.

[4] Ibid., p. 39; and Helfant, David Benaroya, "Seismic Bracing," *Advanced Framing Techniques, Troubleshooting & Structural Design*, (1992), The Journal of Light Construction, RR2 Box 146, Richmond, VT., p. 70.

[5] Dietz, pp. 78-79 and L.O. Anderson, *Guides to Improved Framed Walls For Houses*, U.S. Forest Service Research Paper FPL 31, August 1965, U.S. Department of Agriculture & Forest Service, Forest Products Laboratory, Madison, Wisconsin.

[6] Hyman, Harris, P.E. "Bracing Walls Against Racking," *Advanced Framing Techniques, Troubleshooting & Structural Design*, (1992), The Journal of Light Construction, RR2 Box 146, Richmond, VT., p. 59.

[7] Helfant, "Seismic Bracing,", p. 70.

[8] *National Building Code of Canada*, Canadian Commission on Building and Fire Codes, National Research Council of Canada, sentence 9.23.6.1.

[9] Helfant, *Earthquake Safe*, pp. 18-19.

[10] Based on Chart of Common Nails, Boaz, Joseph N., Ed., *Architectural Graphic Standards, Sixth Edition*, John Wiley & Sons, Toronto, 1970, p. 191.

[11] Based on Simpson Strong Tie Type LUS28 Face Mount Hanger and Beam Hangar Tie Type HU7, from *Connectors for Wood Construction*, Product & Information Manual, Simpson Strong-Tie Company Inc., Pleasonton, Calif., 1995, pp. 30 &16.

[12] Helfant, *Earthquake Safe*, p. 430.

Figure 4D - 1:
Cleaning Up the Contents After An Earthquake

Section D
EVALUATING THE CONTENTS

As part of a "whole house" approach, it is equally important to consider, and if need be, modify the contents of the house. Damage to the contents, or caused by the contents, can make a house unusable for a long period of time. The reactions of contents in earthquakes cause a significant proportion of earthquake injuries and deaths, often when structural damage is minor.

Contents for which seismic restraint is critical to earthquake survival include: furnishings such as file cabinets, bookcases and paintings; plumbing, mechanical and electrical systems; ceilings; light fixtures; stairways; doors; and appliances.

There is an increasing awareness of seismic requirements by more manufacturers of furnishings, appliances and service equipment. Often, guidance may be obtained by simply asking for it, either directly from the manufacturer or through seismic engineering consultants already working for the manufacturer.

CONDITIONS TO CHECK

Item #	
D1	**FURNITURE**
D1.1	❑ **Tall Furniture:** Rooms that contain tall furniture such as bookcases, china cabinets or "high-boy" dressers, present real hazards in an earthquake, as these items are prone to falling. As tall furniture cannot usually be eliminated, its potential for damage may be mitigated by a combination of placement and restraint. The most potentially dangerous locations within rooms are those close to where occupants rest, for example, beds, couches and easy chairs. It is prudent to consider what the furniture and its contents might fall upon if they topple over. Also check if it could block the path to exits.
D2	**APPLIANCES**
D2.1	❑ **Kitchen Appliances:** Refrigerators are of particular concern because they are very heavy, they have a relatively tall and narrow shape and are often top heavy because of loads in the freezer compartment. All of this contributes to their tendency to move or fall over during a quake. If mounted on glides (to facilitate cleaning) they can easily move, trapping or injuring people or blocking their exit path. Also check the presence of gas-fired appliances in the kitchen, whose connections are prone to leakage or breakage in an earthquake.
D2.2	❑ **Wood Burning Stoves:** Free standing wood burning stoves are in common use for residential heating. Installation codes typically require clearances of 400 mm (16") or more from walls, which leaves stoves unsupported and vulnerable to sliding or overturning.
D2.3	❑ **Air Conditioners:** Air conditioners are heavy bulky appliances and can cause severe damage to the building and injury to people during an earthquake, especially where installed in windows, through walls or on the exterior of the house.

RECOMMENDATIONS

❑ **Tall Furniture:**

- Fasten the tall furniture along the top and sides. Fastening can be accomplished using small steel angles or metal straps that are connected to both the furniture and studs in the walls using screws.
- Adhesive backed plastic connector systems are available but provide less seismic resistance because attachment is only to a wall surface, rather than to the structure.
- Try to arrange the internal layout of rooms so that falling items miss beds and sofas, where people may be resting when an earthquake strikes and so that they do not block the path that people would use to exit.

❑ **Kitchen Appliances:**

- Secure major appliances to adjacent surfaces where practical or reduce their tendency to move during an earthquake by placing them on non-skid pads.
- Anchor all gas fired appliances, such as stoves and dryers, to the floor or wall so that connections to the gas piping are not damaged due to movement of the appliances during a tremor.
- When adding restraint elements, care must be taken not to damage the appliance and to position restraints so they are effective. Connecting the restraint using a combination of adhesive type connections on appliances and screw type connections to the wall is one example.

❑ **Wood Burning Stoves:**

- To reduce the potential of injury or fire, the stove should be anchored to the floor and the stove pipe sections secured to prevent separation.
- Anchor stove pipes to the flue exit.
- Secure each segment of stove pipe together with sheet metal screws (for double walled pipe make sure the screws are short enough so they do not penetrate the inner pipe wall).
- If the stove pipe is unsupported for more than 2.5 m (8 ft), provide one mid-height support by running the pipe through a factory-made attic radiation shield, which is in turn braced to the wall to prevent lateral movement.
- Anchor legs of the stove through the hearth material to the building structure.
- It is equally important to ensure that the seismic restraint does not conduct heat from the stove to the combustible materials in the house.

❑ **Air Conditioners:**

- The safest location for an air conditioner is at ground level outside the house anchored to a concrete mat foundation.
- If located in windows or on roofs, they must be secured to the building structure in a manner that will successfully resist earthquake forces. Consult a structural engineer and the manufacturer's engineer for assistance.

Item #	CONDITIONS TO CHECK
D3	**STORED AND DISPLAYED ITEMS**
	Earthquakes often cause damage to these types of furnishings because they move and fall during the motion of the earthquake. So, not only do valuable articles become damaged, in falling they can also injure people in the house. Obviously, the greater the weight of an object, the greater its ability to injure.
D3.1	❑ **Books:** Falling books are a common occurrence during earthquakes, but there are a couple of ways to reduce the hazard. The hazards are exacerbated when heavier books are on higher shelves. Not only can books cause injury when they fall, but they make egress difficult and dangerous, perhaps leading to additional potential injury.
D3.2	❑ **Dishes and Glassware:** When dishes and glassware fall out of storage cabinets, they become damaged and can cause injury to people.
D3.3	❑ **Displayed Items:** Artwork or other objects hung on the walls of a house constitute a potential hazard, especially when the objects or paintings are heavy, or are encased in heavy frames or have protective glass covers.
D4	**LIGHTING AND OTHER ELECTRICAL FIXTURES**
D4.1	❑ **Electrical Fixtures:** Depending on the intensity of the quake, damage to electrical service and fixtures could occur due to earthquake induced motions or structural reactions. Not only could fixtures be torn from their mountings causing direct injury, damage to wiring could cause fire.

RECOMMENDATIONS

- ❑ **Books:**
- One solution is to arrange large books and other bulky items on the lower shelves.
- Another solution is to retain the objects on the shelves by installing a bar or wire across the shelves. This applies for any object stored or displayed on shelves or on top of furniture, ranging from objects of art to canned goods.
- Also, be sure that the shelves themselves are securely anchored to the house structure.

❑ **Dishes and Glassware:**
- The easiest and best solution is have a type of latch that will keep cabinet doors closed during an earthquake. Remember that during the earthquake, the contents of the cabinet will push against the doors, therefore the hardware needs to have a latching mechanism. This approach can also be used for canned goods stored in cabinets, but keep in mind that the weight of the goods and hence the force on the doors will be greater.

❑ **Displayed Items:**
- Heavy objects that are hung on walls should be attached to the house structure, not just the wall surface, with threaded hooks that can be threaded into the studs.
- For lighter objects, it is sufficient to use normal "nail plus hook" hangers, but use an oversize hanger and close the open hook so the hanger wire cannot come out during an earthquake.
- Consider replacing glass over pictures with plexiglass, which is lighter and also much less likely to break in an earthquake.

❑ **Electrical Fixtures:**
- Check the condition of electrical wiring for signs of cracked insulation and poor connections in the wiring boxes.
- Where possible, ensure that the wiring is stapled to the frame of the house in accordance with the Canadian Electrical Code.[1]
- Securely fasten ceiling fans and light fixtures to the frame of the house, including those fixtures that mount on the walls, as well as the ceiling. Install a safety cable on fixtures that represent a potential hazard because of their weight, location, or the materials from which they are constructed.

Item #

CONDITIONS TO CHECK

D5	BUILDING SERVICES AND EQUIPMENT
D5.1	❑ **Water Lines:** Rupture of water lines can cause extensive interior water damage. Fortunately, this is not a common problem because water lines break only when large structural movement occurs. Check for lines crossing zones of potential structural movement or failure.
D5.2	❑ **Gas Lines:** Appliances that can be connected to the gas service may include the furnace, water heater, stove, fireplace, dryer, barbecue, patio heater and swimming pool heater. If a gas line was to rupture, it would make the appliances unusable and could lead to explosion or fire. Check for lines crossing zones of potential structural movement or failure. Also check the stability of the appliance to which it is connected.
D5.3	❑ **Waste Lines:** Rupture of waste lines can cause extensive interior damage. This is more likely to occur in older houses with cast iron pipes, than in newer houses with rigid lines of plastic pipe. Check for adequate support to the structural framing, particularly where waste lines pass through zones of potential structural movement or failure. Confirm support underground when lines are exposed, such as during repairs or modifications.

RECOMMENDATIONS

- Refer to Chapter 4, Section A, page 46 for information regarding the utilities coming onto the property.

❑ **Water Lines:**
- Water lines should be supported every 1.2 m (4 ft).

  Support may consist of:
  - The line being installed through holes in structural elements such as a joist or beam (not recommended, but may already exist),
  - A clip or strap around the line attached to a structural element such as a joist or stud or a similar positive restraint.

- Current installation codes (which vary in different localities) define acceptable supports. However older installations will not likely conform to current standards. Check with local authorities or utility companies for recommended seismic supports.

❑ **Gas Lines:**
- Because gas lines are connected to the house structure and the appliances they serve are connected separately, they tend to move independently during an earthquake. To compensate, a connection designed to flex should be installed between the appliance and the point where the pipe is attached to the structure to minimize the potential of broken connections.[2]

- Gas lines should be supported every 1.2 m (4 ft). See the comments concerning water lines above for appropriate support.

❑ **Waste Lines:**
- Waste lines should be supported every 1.2 m (4 ft) using a method that allows a small amount of movement that is independent of the house structure. See the comments concerning water lines above for appropriate support.

CONDITIONS TO CHECK

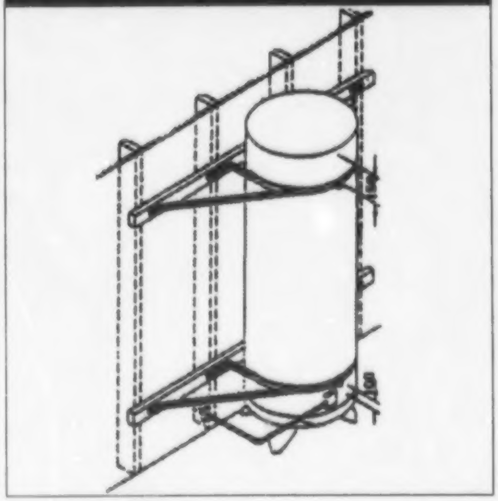
Item #	
D5.4	❑ **Water Tanks:** Because water heaters are heavy, have a tall narrow shape that is relatively unstable, and are usually installed as freestanding appliances, they are very vulnerable during an earthquake. If a gas line was to rupture, it would make the appliances unusable and could lead to explosion or fire.
D5.5	❑ **Furnaces and Boilers:** The conditions for the seismic restraint of furnaces and boilers are generally very similar to those for hot water tanks.
D6	**INTERIOR FINISHES**
D6.1	❑ **Plaster:** The heavy plaster finishes often found in older houses can present a considerable hazard to occupants. Plaster ceilings, for example, may weigh as much as 40 kg/m² (8 lb/ft²). This means that in a room that measures 5 x 5 m (16 x 16 ft), the ceiling would weigh over 900 kg (over 2000 lb). On the other hand, good quality plaster is surprisingly strong and will fail only under large seismic loads. Upper floor bedrooms (and service rooms) in older homes often exhibit lesser quality due to water damage from leaks in roofs or poor plaster workmanship, hence may be more hazardous.
D6.2	❑ **Drywall:** Drywall, also called gypsum board and sheetrock, has been used for wall and ceiling finishes since the 1950s, as a substitute for traditional plaster. When the frame of a house has been built with lateral bracing, the drywall damage from an earthquake is usually modest. The damage to drywall, in multi-storey houses built without seismic restraint, ranges from cracking of joints to spalling of board in areas of high stress.
D6.3	❑ **Masonry Veneers:** Masonry fireplaces and decorative masonry walls are also prone to earthquake damage. Because of the weight of the material, failure of an interior veneer wall can cause severe damage and injury or make egress difficult and perhaps dangerous.

RECOMMENDATIONS

❑ **Water Tanks:**

- The potential hazard can be readily reduced by securing the tank to the floor with bolts (some models provide bolt holes for this purpose) or strapping it to an adjacent wall.

Figure 4D - 2:
Water Heater Restraint



❑ **Furnaces and Boilers:**

- The hazard can be readily reduced by securing the appliances to the building structure and using flexible service connections.
- Refer to Appendix C for a detailed explanation of methods for securing water tanks as a guide for this type of equipment.

❑ **Plaster:**

- The hazard from failing plaster can be reduced by being certain that the plaster is in good condition. Conditions to look for are long cracks and also areas softened by water leakage.[3]
- Repair or replace damaged plaster, especially if located at the ceilings. Replacement will reduce the hazard and usually provides the added benefit of reducing the weight of the finish.
- The combination of lath and thick plaster in good condition has a stiffening effect that can increase the overall earthquake resistance of the structure.

❑ **Drywall:**

- Inspect the wall structure to determine the extent of lateral bracing present. If possible, upgrade the lateral bracing, to minimize damage to drywall finishes due to seismic forces
- Repair or replace damaged drywall, especially if located at the ceilings.

❑ **Masonry Veneers:**

- The procedures for anchoring masonry veneer discussed in Chapter 4, Section B, page 68, should be consulted when masonry is used, even as a decorative element inside the house.

Item #	CONDITIONS TO CHECK
D7	**WINDOWS AND GLASS**
	Windows constitute a hazard from collapse due to large openings in the building structure (soft storey). Picture windows, sliding glass doors, bay windows, glass walls, and walls of glass block present the very real hazard of severe injury from sharp glass and costly replacement from breakage during earthquakes. Much of the earthquake induced damage to the structure, and consequently to finishes and glass, occurs around the windows. The large glass areas introduce weaker points in the structural frame of the house. The stresses concentrated at the corners frequently cause the glass to shatter.

RECOMMENDATIONS

- For a more complete discussion of "scft storeys", refer to Chapter 4, Section B, page 78.
- Changing windows to laminated or tempered safety glass, or installing security or safety film, will reduce dangers from large sections of sharp flying glass. Consider the critical areas near beds, reading areas, and along escape paths such as corridors, stair landings and entries, for protection. However, some glass breakage is inevitable during strong quakes.
- The application of safety film has several additional benefits. The film can be used to control incoming sunlight, reduce heat loss through the glass, and increase the security of the house. Solar fiims themselves provide only minimal protection due to their single lamination composition.
- Provide a designed bracing system as part of the structural framing around the window opening. The bracing redirects the quake forces around the opening and reduces the likelihood of glass breakage.

[1] *Canadian Electrical Code*, CSA - C22.1 - 1994, Canadian Standards Association.

[2] California Governor's Office of Emergency Services and Federal Emergency Management Agency, *A Guide to Repairing and Strengthening Your Home Before the Next Earthquake*, February 1994, p. 31.

[3] Yanev, Peter I., (1991) *Peace of Mind in Earthquake Country*, Chronicle Books, 275 Fifth Street, San Francisco, CA., pp. 155-156.

5. DECIDING HOW TO UPGRADE FOR EARTHQUAKE RESISTANCE

This chapter explains actual design and construction strategies for upgrading and provides a weighted assessment of the opportunities various renovations provide for seismic upgrading.

INTRODUCTION

There is nothing easy about the decision to seismically retrofit an existing building. Retrofit is costly, time-consuming, and disruptive to those living in the house. It increases the capital cost of a house, impacting mortgage/rent/loan calculations. It can pose architectural, engineering and logistical challenges. It can affect the historic or architectural integrity of the house.

What is doubly difficult is that the benefit is easy to discount. All the cost and hardships are immediate, yet the spectre of an earthquake is almost an abstraction, something that may appear remote, far off in the future. People acknowledge the certainty of future earthquakes, but assume that they will not be personally affected.

These factors combine to make decisions about the degree of seismic upgrading and associated financing difficult. No one knows how, when, or with what force an earthquake will strike any particular locality. The odds may appear to favour the owners who assume that the earthquake will not strike during their period of occupancy.

However, after an earthquake nearly every house's owners/occupants wish they had done more, and they are thankful for any upgrade work they have done.[1]

The process of using the preceding chapter's checklists to analyze a particular house and its surroundings has involved the following:

- Assessing the property;
- Assessing the exterior condition and design of the house in terms of construction quality, design appropriateness and in-built hazards;
- Assessing the foundations;
- Assessing the connections between the foundation and the wood frame above;
- Assessing the supporting elements;
- Assessing the diaphragms (floors and roofs)
- Assessing the structural connections between as many of the structural components as possible;
- Assessing the interior finishes, contents and furnishings.

The next step in proceeding with upgrading seismic resistance involves deciding what to do, how to do it, and when.

DECIDING TO UPGRADE

There are no laws and no insurance requirements that compel homeowners or occupants to upgrade their houses to resist earthquakes. The only upgrades required pertain to large additions or major renovations, and not in every jurisdiction.

If major renovations are proposed with other objectives in mind, some building codes provide for varying degrees of general code upgrading of a house, depending on the proportionate value of the renovations. In other words, while a major extension, perhaps doubling the size of a house, would likely require that the entire house be brought up to current code standards as regards sprinklers, exits, etc., simply adding a new back door would not likely require any work elsewhere in the house.

Ironically, because Canadian building codes have few or no seismic requirements governing houses, the above-noted major extension could take place, in all likelihood, without the need to so much as tighten one anchor bolt, let alone add any!

Hopefully, the occupant of a house that exhibits any number of Risk 3, Loss of Life deficiencies will move those upgrades to the top of the family's "To Do" list for house renovations. In fact, since the vast majority of North American homeowners who have experienced a major earthquake feel they were unprepared, including those who made many disaster preparations, the sooner the better.

Upgrading Concurrently with Other Renovation Projects

Table 5-1 lists some of the more typical interior and exterior renovation projects undertaken by Canadian home-owners and occupants, together with their possible seismic upgrade opportunities.

Table 5 - 1: Upgrading Opportunities

Renovations Adding Value to the Home[2]	Potential Seismic Upgrade Opportunities	Risks Addressed		
		1	2	3
Kitchen Renovations	Braced wall additions to kitchen level			
	Floor diaphragm upgrade			
	Cabinet door and drawer latch upgrade			
	Flexible connections to gas appliances			
	Window reinforcement			
	Hold-downs between floors			
Bathroom renovations	All as for kitchen except appliance connections			
	If on upper floor, hold-down connections at roof structure (or attic structure) with supporting walls			
Interior painting and decorating	Fastening (secure) of furniture and contents, especially shelving units, bookcases, etc.			
	By choice of finishing materials, possible braced wall improvements			
Main floor family room addition	Opportunity to create a "safe" room			
	Floor diaphragm upgrade			
	Braced wall additions to family room			
	Hold-downs between floors			
Finishing basement	Braced wall construction			
	Anchor bolt addition or improvement			
	Sill plate condition and connection to wood framing			
	Foundation improvements			
	Furnace, hot water tank, oil tank, etc. restraint			
New or converted heating system	Furnace, hot water tank, oil tank, etc. restraint			
New windows and doors	Resolution of "soft storey" conditions			
	Security films to reduce shattering			
Exterior recladding and refinishing	Access to structure under cladding, allowing braced wall upgrades, addition of hold-downs and ties, etc.			
	Choice of cladding to improve seismic performance			
	Addressing chimney issues			
Central air conditioning	Furnace, hot water tank, oil tank, etc. restraint			
	Access to various wall and floor assemblies during construction, for verification of standards of seismic resistivity			
Energy efficient home upgrades	Solar control window films with security component, to reduce glass shattering			
	Furnace, hot water tank, oil tank, etc. restraint			
	Access to various wall and floor assemblies during construction, for verification of standards of seismic resistivity			
Attic renovations	Protection of roof and lower floors from chimney collapse			
	Chimney repair, strengthening or replacement			
	Hold-down connections at roof structure and supporting walls			
	Bracing of roof membrane			
	Bracing of gable end walls			

The Cost of Seismic Upgrading

In residential renovation work, costs are seldom determined in the same fashion as for new construction. The potential disruptions to home life and attendant scheduling of construction activities to permit home life to carry on, the lack of foreknowledge as to what lies behind a wall or under a floor, the requirements of working in existing, confined spaces and maintaining a neater work site than would be required for new construction - all of these conspire to make cost estimating problematic.

These factors also result in often widely divergent estimates by different contractors, based upon their varying experience with working in existing houses.

Notwithstanding these aspects of renovation, it is possible to find authoritative written material specific to the costs of residential renovation work. Refer to Appendix A for some of these sources.

Since each house is unique and the details of any renovation vary widely, the best way to evaluate the costs attributable to seismic upgrading is to price the costs of materials and methods that go beyond conventional construction. Table 5-2 establishes unit costs for performing various building operations, identifies a seismically upgraded version and prices this variation. By calculating the cost increase for the seismically sensible approach and multiplying by the number of units involved in the renovation, a reasonable estimate of upgrade costs may be established.

Table 5 - 2:
Unit Costs of Conventional Versus Seismically Sensible Construction

Conventional Construction		Seismically Sensible Construction[3]	
Construction Operation	**Installed Unit Price***	**Construction Operation**	**Installed Unit Price**
Anchor Bolts @ 2.4 m centre to centre (o.c.), length 170 mm	$1.25 per metre of wall ($0.40 per lineal foot)	Anchor Bolts @ 1.2 m (4') o.c., length 250 mm (10") Anchor Bolts @ 1.2 m (4') o.c., length 430 mm (17") for new construction	$3 per lineal metre of wall ($0.90 per lineal foot) $6 per lineal metre of wall ($1.80 per lineal foot)
Hold-downs	not required in standard practice	Hold-down anchors, three @ each corner, 1500 kg (3300 lb) uplift each	$130 per corner
Wood column base	$6 per column	Wood column base, adjustable, 1000 kg uplift	$15 per column
150 x 150 mm (6" x 6") Wood column to 89 mm x any dimension (4" x any dimension) beam connectors	$10 each	150 x 150 mm (6" x 6") Wood column to 89 mm x any dimension (4" x any dimension) beam connectors, 1365 kg (3005 lb) uplift	$75 each
Nailed joists to sill plate	standard practice	Metal angle connectors between sill plate and floor joists	$2 per lineal metre of plate ($0.60 per lineal foot)
Nailed rafters to top plate	standard practice	Metal angle connectors between top plate and joists or rafters	$2 per lineal metre of plate ($0.60 per lineal foot)
9.5 mm (3/8") plywood sheathing nailed 150 mm (6") o.c. edges, 300 mm (12") o.c. field	$25 per 1.2 m x 2.4 m (4' x 8') sheet (40 nails per sheet) pneumatically nailed	12.7 mm (1/2") plywood sheathing nailed 75 mm (3") o.c. edges, 100 mm (4") o.c. field (90 nails per sheet) pneumatically nailed	$30 per 1.2 m x 2.4 m (4' x 8') sheet
Floor-to-floor connectors at middle floors	not required in standard practice	Floor-to-floor connectors, 3 per corner, 1500 kg (3300 lb) uplift each	$250 per middle floor corner
		Security film on window	$ 40-50 per square metre ($4-5 per square foot)
		Strapping down hot water tank	$75[4]

* Actual costs may vary from 93% to 117% of those stated, depending on the location within Canada.

Creating a Master Plan

Many multi-building construction projects involve several phases of construction over several years. Each phase is complete in itself and the house is salable at its completion.

Similarly, many homeowners realize that over their lifetime, houses involve many phases of renovation, reconstruction and additions. Hopefully each provides an incrementally improved environment.

The master planning of renovations to a house is seldom a linear process. Rather, it involves cycles of analysis, discovery, synthesis and creation to gradually evolve a more coherent vision of the successive refinements. Whether it is reorganizing or redecorating an existing space, or adding new space, thus allowing a reworking of existing functions in a house, master planning is a process of making incremental improvements in order to achieve overall concepts.

Seismic upgrading could be seen in the same light. If each renovation incorporated an appropriate seismic upgrade component, as the house became incrementally more of a "home," it would at the same time become an increasingly "seismically sensible" house.

Creating an Earthquake Update Master Plan

There is one key difference between the renovation master plan for a house and the requirements of upgrading for earthquake resistance. That difference, as explained in Chapter 4, is the risk of loss of life, loss of structure or major loss of contents associated with the existing condition of the house, its contents and the property.

The priority of most house renovations is driven by "human" factors such as the evolution of the family in the house, the aging of the house itself, and the fashions of the day. The urgency of earthquake upgrading is driven by the realization that some upgrading measures will only be effective if attention is paid to certain basic items. While each house is unique (hence the checklist approach), research indicates that a relatively small number of upgrade measures have a relatively major impact on the general earthquake resistance of a particular house. For most houses, these key measures include:

- Anchoring frame structures to foundations,
- Bracing cripple walls,
- Removing, reinforcing or modifying masonry chimneys.

Failure to attend to these key measures has been blamed for most of the major damage to houses, injury and loss of life in earthquakes such as those near San Francisco (Loma Prieta), Los Angeles (Northridge) and Kobe, Japan.

Once these key aspects are attended to, a second tier of measures should be addressed, whose implementation will further improve the safety of a home and its habitability after an earthquake, as well as further reducing the three risks noted above. But this second group of measures will only be effective in further reducing risk if the first tier of key measures noted above has been addressed. For most houses, the second tier of measures includes:

- Bracing walls, floors and roof at and above the first floor, including openings in them,
- Adding bracing to appendages such as carports and verandahs,
- Bracing water tanks and furnaces and upgrading their connections to services.

Appendix H, Checklists, includes forms for summarizing the deficiencies of a particular house, including the associated degree of risk and a space to indicate upgrade plans. To further assist the *Guide* user, Appendix I includes an Earthquake Upgrade Master Plan form. Refer to the case study in Appendix F for an example of the use of these forms.

The material in this *Guide* is not intended to produce a master plan for the long-term development of a single family living environment. However, it may help to order the steps to achieving that master vision, as well as "fleshing out" various plan components in order to achieve maximum seismic resistance with a minimum outlay of extra time and money.

[1] California Office of Emergency Services, Bay Area Regional Earthquake Preparedness Project Fall 1992, Seismic Retrofit Incentive Programs, p. 17.

[2] Private communication from Mr. T. Marshall, CMHC, January 1996, based on information from The Appraisers Institute of Ontario.

[3] Conventional costs are taken from R.S. Means Company, Inc, *Residential Detailed Costs 1996 - Contractor's Pricing Guide*, Kingston, Massachusetts. Seismically sensible costs are taken from the same source, except where specific hardware is intended, prices are taken from Simpson Strong-Tie Company, Inc., *Revised Canada Price Book for Catalog C-95H-1, 1995.*

[4] As advised by Jay Lewis, TerraFirm.

6. CONCLUSIONS
THE SEISMICALLY-SENSIBLE HOUSE

This chapter presents conclusions regarding the ways to upgrade houses from the point of view of each potential group of readers. It makes summary recommendations regarding actions that readers can initiate immediately in order to take a proactive approach to upgrading aspects that are in their control or under their influence.

> "...There are two quake scenarios for southwestern B.C. The first is relatively moderate... It would be very bad. Major bridges would collapse. Electricity, water and gas mains would fail. Raging fires would erupt. Soil would liquefy and dikes would slump, flooding as many as 250,000 homes in the Fraser Valley. About 200 people would die and the financial costs would run to $32 billion.
>
> "As bad as this sounds, the second scenario is much worse... It would produce a catastrophe unlike any that has ever struck North America... Some villages would simply disappear. Older parts of Victoria's and Vancouver's downtown areas, old bridges and scattered unreinforced masonry buildings within 150 kilometers of the epicentre would collapse.
>
> "One day soon - no one knows exactly where or when - the subterranean forces will be unleashed... the earth beneath southwestern B.C. will come unstuck. The land will convulse... Hundreds, perhaps thousands, will die.
>
> "We have a very big problem. The California quakes, the Kobe quake... they could be insignificant compared to what could happen here."[1]

CREATING "THE SEISMICALLY SENSIBLE HOUSE"

By following the recommendations contained in this *Guide*, no house need be at risk of major damage or collapse in an earthquake. Each participant in the design, approvals and construction phases of renovations or new houses has a part to play in creating a house that balances all of those often complex aspects of the processes of creation and renovation with due consideration for earthquake resistance, creating what the *Guide* refers to as a "seismically sensible house."

ACTIONS BY DESIGNERS

As house owners, lenders, insurers and municipal officials become sensitized to seismic design issues, two things will happen to the design marketplace:

1. A "niche" will develop for those designers immediately capable of assisting with seismic upgrading, integrating seismic upgrading with new renovations and designing new houses that are "seismically sensible."

2. Designers will upgrade their skills to participate in an increasingly large component of the design and construction field. Now is the time to implement "seismically sensible" design.

In terms of design professional practice, where a designer is retained to provide construction phase services, there is no substitute for timely field review. This must include all aspects of construction noted in the *Guide*. As with most renovation work, the designer must also be prepared to evaluate emergent conditions on site and recommend additional remedial seismic work where conditions as uncovered vary from design assumptions.

ACTIONS BY PLANNING OFFICIALS

Many houses, especially older houses in established residential areas, do not conform to current zoning bylaws. The most common nonconformity is probably insufficient setbacks. Some of the recommendations of this *Guide* may best be implemented by further minor incursions into setbacks, such as the construction of modest "buttresses" to support existing foundations or walls above and strapping with its attendant cover strips. These minor incursions should be accommodated, either in the text of zoning bylaws, or by establishing a process that encourages owners and occupants to seismically upgrade.

Many municipalities have the expertise for review within their staff complement. Those that do not could retain outside consultants to perform evaluations, or simply rely on the certifications of a design professional that a particular course of action is appropriate.

Conversely, many zoning bylaw clauses hinder "seismically sensible" design of renovations and new houses. For example, zoning may place:

- prohibitions on covered entry porches (assuming solid construction) thus eliminating a means of creating a safe exit pathway, in the event of a tree or a neighbour's chimney falling on the house;
- severe limits on other "appendages" such as covered walkways, trellises and similar garden structures, thus eliminating an opportunity to use these elements as additional seismic braces;
- limitations on methods of counting floor space, actually penalizing thicker walls, which may be more seismically appropriate;
- provisions that effectively require asymmetrical buildings, highly articulated facades and massing, etc., which may suffer greater earthquake damage than simpler structures.

Zoning bylaws should be reviewed to identify aspects that prevent seismic upgrading and mitigate against "seismically sensible" design.

Bylaws governing renovations should be particularly scrutinized. Those municipalities that do not choose in-house review could retain outside consultants to perform evaluations, or simply rely on the certification of a design professional that a particular course of action is appropriate.

ACTIONS BY BUILDING OFFICIALS

Not surprisingly for a technical guide, this document has identified many areas for action by building officials.

The *Guide* has identified seismic elements that may be more completely covered by codes. On most houses built under Part 9 of the National Building Code (as adopted in the various provinces and territories) no professional assurances by architects or structural engineers are required, either as to design or construction. Either these assurances should be required in seismically sensitive areas, or the NBC document itself should be revised.

Sections of Part 9 of the 1995 National Building Code that should be reviewed regarding seismic issues include:

- 9.3 - to consider higher compressive strengths for concrete elements, to require most or all concrete in seismically sensitive areas to be reinforced, and to review minimum lumber grades for specific end uses;
- 9.4 - to qualify (that is, make more stringent) the permission to design to Part 9 in lieu of Part 4; to add Appendix A notations recommending procedures for determining bearing pressures and general seismic suitability; to be more specific about mitigating design measures to address high water tables, soil movement, retaining walls and walls supporting drained earth;
- 9.9 - to consider adding provisions facilitating or mandating safe egress, that is protection of exits from adjacent structural collapse or collapse of trees and service poles; to make safety chains on egress lighting (at least) mandatory;
- 9.10 - to permit reductions in limiting distances and dimensions to combustible projections associated with structural elements designed for seismic resistance, to less than 1.2 m for renovations to existing construction without having to use sprinklers, closures, glass block or wired glass that would not otherwise be required; to mandate the provision of at least one portable fire extinguisher in association with any renovation application;
- 9.12 - to review minimum foundation depths with seismic design in mind;
- 9.15 - to review prescribed foundation design measures for seismic appropriateness; to require reinforcing steel in footings and foundation walls; to specify better measures for lateral support;
- 9.16 - to require reinforcing steel in slabs;
- 9.17 - to better define and describe steel column sizes, materials and fastenings, especially to other materials such as wood and concrete; to review nailing prescriptions for wood columns; to review design specifications for unit masonry and concrete columns;
- 9.18 - to prescribe approaches for anchoring wood frames to foundations in a crawl space situation;
- 9.19 - to prescribe approaches for anchoring roof frames to walls below;
- 9.20 - to review current earthquake reinforcement specifications for above-grade masonry; to review the appropriateness of lintel span table for seismic conditions; to review bonding and tying requirements for masonry construction, especially masonry veneers; to review anchorage of masonry walls to wood frames; to review and probably add tying requirements for masonry corbelling; to review corrosion resistance requirements for anchorage, bonding and tying devices;
- 9.21 - to upgrade requirements for lateral support of chimneys; to suggest in Appendix A the limitation of masonry chimneys above roof lines;
- 9.22 - to add lateral restraint requirements for hearth-mounted stoves and their flues;
- 9.23 - to add seismic requirements throughout the wood framing section, including: anchor

bolting; nail dimensions and spacing; conditions where anchorages other than nails and anchor bolts are mandated; minimum sheathing materials, thicknesses and nailing patterns;

- 9.24 - as for 9.23 but as applicable to sheet steel stud framing;
- 9.26 - to eliminate or restrict the use of heavy roof materials in seismically sensitive areas and/or to upgrade fastening standards where these materials are permitted;
- 9.27 - to review the minimum requirements of cladding attachment specifications for seismically sensitive areas;
- 9.28 and 9.29 - to review finish specifications with regard to seismic requirements;
- 9.31 and 9.33 - to encourage or require flexible connections for gas and water to hot water tanks and furnaces;
- 9.34 - to require safety chains on ceiling mounted lights, fans, etc.;
- 9.35 - to upgrade garage and carport specifications with regard to seismic requirements.

On the enforcement side of the building permit process, inspection officials should be trained in the seismic aspects of Part 9. The list of mandatory inspections should be expanded to include:

- Prior to pouring concrete - verifying that anchor bolts are in place, properly spaced along perimeter and in thickness of wall, and properly embedded (note: errors may be corrected after pouring, using anchors drilled in and set in epoxy);
- Pre-boarding - verifying that anchor bolts are in place, including verifying that washers and nuts are attached and tightened; checking that other seismic anchorages are in place and properly (i.e., completely) nailed or bolted;
- Mechanical inspections - checking that there are flexible connections to hot water tanks and furnaces;
- Electrical inspections - checking that there are safety chains on certain fixtures.

As an alternative, and possibly as an additional responsibility for both Part 9 and Part 3 buildings, official letters of assurance by registered professionals for a project may be expanded to be explicit regarding seismic requirements for design and field review. This has already occurred in some jurisdictions regarding seismic restraint of larger mechanical and electrical systems.

ACTIONS BY INSURERS

The insurance industry admits it is unprepared for a major earthquake in an urban area. Its premiums and deductibles vary widely. Insurance industry-sponsored research into earthquake loss patterns associated with various types of house design and construction is still in its infancy.

At the present time, the authors are not aware of any insurers who offer reduced earthquake premiums for owners who have their houses professionally upgraded for seismic resistance. Such upgrading could be readily determined by a professional using this *Guide* as a starting reference. The program could be similar in style to the New Home Warranty Program. Homeowners should check with their agents for this option.

ACTIONS BY BUILDERS

People want their homes to be safe and secure. More people are choosing to stay in their houses longer and to renovate, upgrade and enlarge rather than move and trade up. This, combined with a higher level of awareness of the threat of earthquakes and the relatively small cost of seismic upgrading, creates a market niche opportunity for leading-edge builders.

The incremental cost, for example, of anchoring a wood frame to a concrete foundation in accordance with current codes is in the order of $200. The cost to augment the size and spacing of anchor bolts and similar foundation upgrades as recommended by this *Guide* is perhaps another $1,000, a small investment if it keeps a house from falling off its foundations and becoming

unrepairable.* Many of the recommendations of this *Guide* involve costs of this order of magnitude. If builders are nervous about such costs, they should quantify the incremental increases for a given project and present the tally as an "extra" to the house owner. This is a much better approach than arbitrarily deleting seismic provisions without consulting owners.

During construction, builders need to pay attention to the procedures laid out in the *Guide*, for example, checking anchorage, nailing patterns, bolting and use of correct connectors. Where unforeseen conditions are encountered, the designer should be consulted for direction.

ACTIONS BY HOUSE OWNERS AND OCCUPANTS

Although building regulations do not usually require the involvement of an architect or a structural engineer in the design or construction of a new house or house renovations, engaging these professionals on a project, even a modest one, will provide greater assurance that a trained professional has reviewed the existing house's design and construction and integrated appropriate seismic upgrading into the work. The extra liability these professionals carry, as well as their legislated duty of public care, translate into additional comfort for the owner/occupant. On any building site, no matter what the size of the project, registered architects and professional engineers retained for that project are the only parties who have unlimited liability in perpetuity for their work on the project.

The cost of engaging professional architects and engineers for a renovation will generally be less than the deductible associated with earthquake insurance for the house. The cost of engaging these professionals to perform a seismic review such as provided for in this *Guide* may be less than a few years' worth of earthquake insurance premiums.

Canadians living in earthquake prone areas of the country spend almost $15 billion on renovations annually.[2] If a small portion of those funds were used by home-owners to undertake the most basic recommendations of this *Guide*, thousands of houses slated for renovation work this year would have much increased chances for survival in an earthquake.

IN SUMMARY, REMEMBER ...

Implementation of the *Guide*'s recommendations in any house will lessen the possibility of personal injuries and property damage in the event of an earthquake.

1 Quotes from Dr. Garry Rogers, Geological Survey of Canada, "Earthquake Coast," by Daniel Wood, in *Beautiful British Columbia*, Bryan McGill Ed., Vol. 38, No. 1, Spring 1996, Victoria, B.C.

2 "Renovation Market Outlook" in *National Housing Outlook Fourth Quarter 1995, Special Supplement*, CMHC, p. 4.

* Table 5-2, Chapter 5 of this *Guide*. The figure of $1,000 incudes an allowance for increased length and quantity of anchor bolts, the addition of hold-down connectors and upgrading the thickness and nailing of plywood shear walls.

APPENDIX A

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APPENDIX B

PROFESSIONALS INVOLVED IN SEISMIC DESIGN

PROFESSIONALS

Individuals wishing to proceed with seismic upgrading work may look to the following professionals for possible assistance.

Architects

Architects traditionally act as the prime consultants for many design and construction projects. In most provinces they are required by law to be involved in all but the smallest non-industrial projects. However, they are generally not required by law to be involved in new house design or house renovations.

The qualitative reasons for using architects include:

- They have generally trained for five years and apprenticed for three to five years in order to earn the designation "architect."
- They are trained as problem solvers and retain "the big picture" of client needs and desires.
- They are experienced in expediting projects from start to finish, including all of the non-design items.
- They are independent of contractors and suppliers, and receive no payment or commissions for use of specific products or suppliers, thus avoiding conflicts of interest.

A key practical advantage of using an architect is that of all the parties involved in the design and construction of a project or renovation, only the architect and professional engineer(s) are governed by provincial legislation, which leaves them with perpetual and unlimited liability to the client and to the general public for the work they have designed. This extensive liability and responsibility may cause registered architects and professional engineers to include in their scope of services more of the services noted below under "Professional service contracts," and they will naturally charge higher fees for a greater scope of work.

The only disadvantage of using an architect or a professional engineer is that, because they provide a higher level of service than others may, their fees are commensurately higher.

Designers

Only architects and engineers registered with a provincial architectural or engineering association are entitled to use the designation "architect" or "professional engineer." Others may call themselves "designer" or "residential designer," but regardless of title, they are not governed by provincial legislation, leaving home-owners with much reduced protection for any errors or omissions in their work.

Some designers who specialize in residential work may be able to offer more focused services than an architect who has less residential experience. Their fees may also appear lower, however this should be weighed against their lack of liability for errors or omissions. Their scope of services should also be verified as to completeness.

Design Counselors

Design counseling is a relatively new approach to the delivery of design services. A design counselor may be a trained professional such as an architect or engineer, or may be a designer or technician.

The concept of design counseling is to provide the client with just those services needed to complete a specific design related task, without requiring the client to contemplate a major project. It may be perfect for home-owners and contractors wishing to obtain assistance with some aspect of seismic upgrading, perhaps on a project with another professional responsible for basic design, or a project of a size where a prime consultant is felt to be unnecessary. Design counselors might also be trained to perform the seismic inspections contemplated by this *Guide*.

Since design counsellors may or may not be registered professionals, their liability for errors and omissions will depend upon their professional qualifications.

Structural Engineers

The stresses that earthquakes place on houses are complex, and will vary with individual sites and variables such as house configurations and age. The details recommended in this *Guide* will improve the earthquake performance of almost any house, however the *Guide*'s authors cannot guarantee or warranty performance. Where a greater degree of design warranty is important, or where the existing house design or proposed alterations are in any way complex or suspect, a structural engineer is best suited to analyze the problems, make recommendations and structural designs and verify that they are properly constructed. Some structural engineers have a particular interest and expertise in seismic design, and a few combine that expertise with single family residential experience.

SELECTING CONSULTANTS

In many ways, selecting consultants is no different from selecting contractors. Some tips:

- Professional associations will usually provide prospective clients at no charge both with lists of practitioners and with recommended procedures for choosing them.
- An interview, even over the telephone, is essential as a means of determining whether a particular consultant is compatible with the prospective client. It is important to speak with the person who will be doing the project work.
- Single family residential work with a seismic component is a new way of looking at a renovation or new construction project, so consultants may have a sparse portfolio of completed work. Question the consultant's understanding of seismic design principles and ask specifically how these principles might affect the contemplated work.

The sections immediately below deal with the practicalities of working with seismic professionals.

Verifying the Consultants' Qualifications

Many of the steps involved in hiring consultants are no different than those for hiring contractors (See Appendix E).

- Even on the smallest job, get proof that the person you are dealing with has a business licence as well as appropriate professional qualifications.
- Architects and professional engineers are now required in some jurisdictions to maintain workers' compensation standing. Call the provincial Workers' Compensation office to ensure the consultant has coverage and is in good standing, that is, has been paying assessments.
- Ask the consultant for proof of liability insurance, which usually consists of a one or two page document that can be verified by telephone. The usual minimum coverage is $250,000 per occurrence. If the consultant has no insurance, re-evaluate the choice, since most consultants have no other significant assets that could support a claim for errors or omissions.
- Contact the people provided as references and ask questions that will help you decide if the consultant will satisfy your needs.

Professional Service Contracts

Provincial architectural and engineering associations have standard contract forms, often including short form versions that may suffice for residential renovation work. Alternatively, consultants may have suitable contracts in letter form. In any case, get a written contract that clearly spells out:

- The scope of the project;
- The complete scope of services being provided by the consultant;
- The responsibilities of the consultant and the client;
- The basis for payment of fees and expenses, including amounts, when to be invoiced and paid;
- The consultant's liability, both as to scope of services and limits of liability;
- What to do in the event of any disputes. Mediation or mediated negotiation is the least costly approach to dispute resolution; arbitration may be the next choice as regards cost; legal action is by far the most expensive.

A "full service" contract such as an architect might propose would likely include these components:

- A general review of the site and in the case of a renovation or upgrade, the balance of the house; this is consistent with the inspection that this *Guide* assumes will be conducted as per the *Guide* checklists;
- Advice to the client as to any other work that may be appropriate or required in relation to the contemplated work, either by virtue of common sense or required by building or planning officials;
- Full design services, including preparation of designs, applying for necessary permits, preparation of construction drawings and specifications, as well as those items noted below;
- As many field reviews as they deem appropriate for a project; specified field reviews at certain stages of the work, typically before certain work is covered up;
- Preparation and administration of construction contracts, including certifying payments and maintaining hold backs of money to cover deficiencies and any liens.

Refer to Appendix E for tips on working with contractors, most of which an architect will take responsibility for when retained for a project.

Typically, a house owner should budget 10 to 15 per cent of the cost of construction for full service architect fees. This amount may be reduced if the client is providing usable background information and makes other concessions regarding the architect's scope of services.

Designers charge for their work on a variety of bases, but usually they charge a fixed fee based on project complexity and extent of services. In exchange for what often appear to be lower fees, many designers will have no part in the construction phase of a project.

Structural engineers will usually charge an hourly fee for their work, since especially during construction, they may be called on to a greater or lesser extent, depending on what demolition reveals.

Expect to pay a design counsellor on an hourly basis, including travel time to and from a construction site and telephone consultations where required. Most design counsellors prefer to be paid by credit card, which eliminates accounting overhead at a cost savings to the client.

All of these services, in combination, will result in a better completed project. The architect may agree to eliminate some of these services where provided by others.

Professional Fees

Professionals generally charge on the basis of time expended, regardless of how they choose to quote fees or structure invoices and contracts. Any time savings that they can expect to receive should be passed on to their client.

To save professional time, consider the following services, which any home-owner might be able to perform:

- Site investigation and research: collecting available site information from city hall, including talking with permit staff to discover what additional requirements might impact on the proposed project; assembiing any existing drawings or surveys of the house;
- Measuring the site and recording existing conditions: taking detailed measurements in the areas where renovations are contemplated; taking photographs of existing conditions;
- Compiling a design file: clipping images of work that appeals to the client and may apply to the proposed project; recording one's thoughts about the proposed project and the desired outcome(s) of the work;
- Keeping a project construction diary: keeping daily records of the work and crews, including photographing work in progress; compiling words and images for the professionals' use.

INSPECTING THE WORK OF PROFESSIONALS

It is not unwise to regard consultants working on a project as being service contractors, that is, to review their work in a manner similar to that of a contractor. For example:

- Check progress on design and documentation work regularly. Insist on "signing off" work at the concept design stage, the final design stage and the construction document stage just prior to seeking a contractor. Keep copies of these sign-off documents and compare previous sign-off documents to the work next presented. If the work is diverging from the last sign-off stage, question why and do not authorize the consultant to proceed until satisfied.
- Make sure the consultant inspects the work as often as agreed to, and whenever "gut feeling" suggests a professional overview is required. Get written inspection reports. Ask the consultant to take photographs and provide a duplicate copy.
- At the end of the project, perform a detailed inspection. Municipal inspectors are not usually concerned with the details of finishing and similar quality concerns. If unhappy with the quality of anything, be up front about it. If work is not satisfactorily completed or remedied, hold back fee payments until satisfied.

Warranties and Guarantees

As noted above, only architects and professional engineers usually carry errors and omissions insurance. For contractor warranties and guarantees, refer to Appendix E.

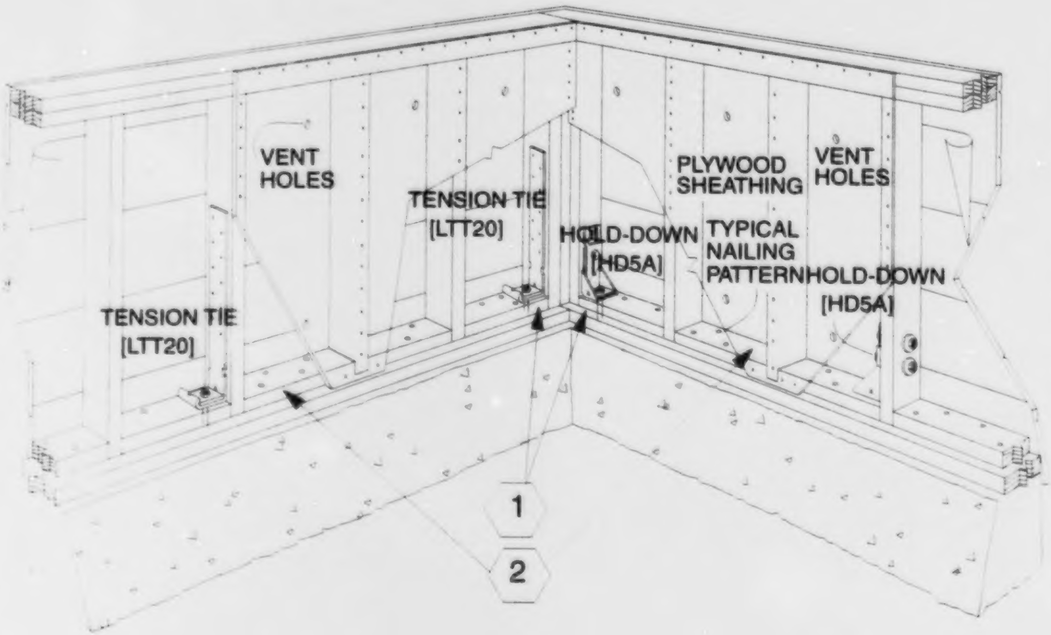
Where completed work appears deficient, contact the architect or designer to coordinate remediation with the contractor. If the deficiencies are minor, the consultant may suggest dealing directly with the contractor, but this determination is best left to the consultant.

APPENDIX C

TECHNICAL DETAILS FOR SEISMIC UPGRADING

APPENDIX C
TECHNICAL DETAILS FOR SEISMIC UPGRADING

The accompanying collection of technical details and information provides useful references for seismic upgrade measures. They have been developed for general conditions and may not apply to specific buildings, however they do give general guidance on what to consider. It is not possible to identify every condition or potential solution that will be encountered when strengthening a house, and earthquake design professionals should be relied upon when questions arise. Before starting any work, check with your building department for specific local building requirements.



NOTES:

THIS SKETCH SHOWS TWO TYPICAL RETROFIT SHEARWALL EXAMPLES IN A CRIPPLE WALL CONDITION. USE ADDITIONAL TIES NOT SHOWN IN THIS SKETCH TO TRANSFER VERTICAL AND HORIZONTAL LOADS BETWEEN THE CRIPPLE WALLS AND THE FIRST FLOOR WALLS.

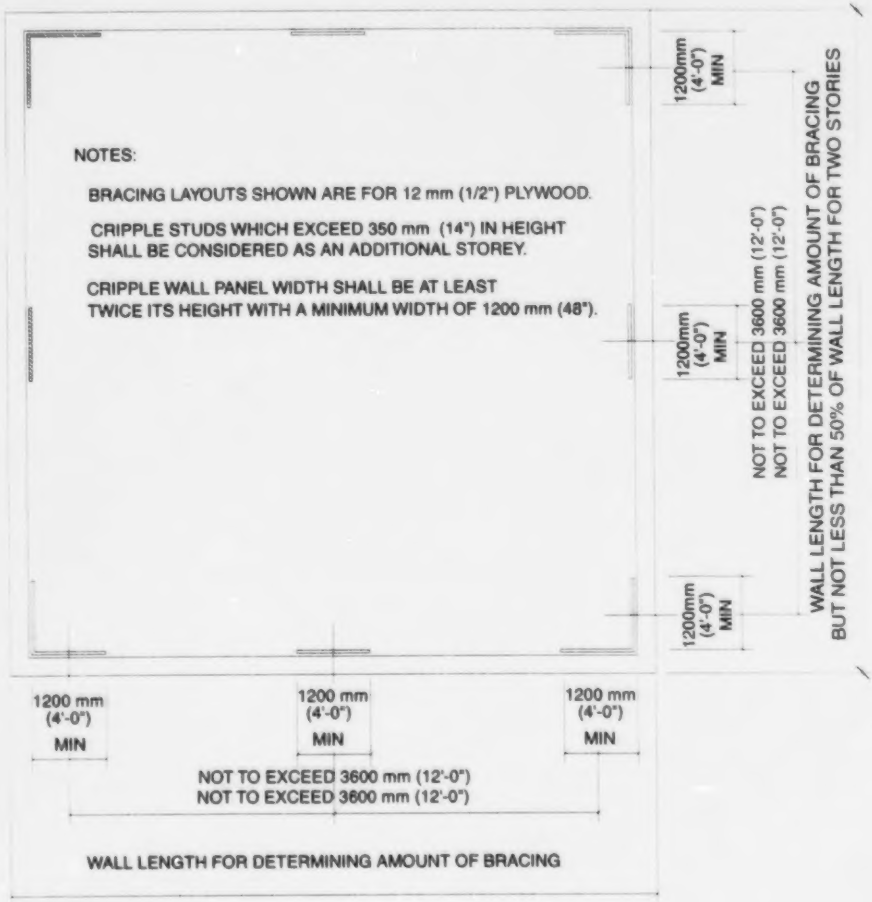
THIS IS A GENERAL SKETCH; STUD SPACING AND HEIGHT SHOULD CONFORM TO LOCAL CODES.

1 HOLD-DOWNS AND TENSION TIE [LTT] CONNECTORS SHOW APPROXIMATE SIZE AND LOCATION RELATIVE TO CORRECT INSTALLATION IN A SHEAR WALL, SPECIFICS TO BE DETERMINED BY BUILDING DEPARTMENT.

2 SILL PLATE BLOCKING TO ACCOMODATE PERIMETER NAILING OF NEW PLYWOOD SHEATHING.

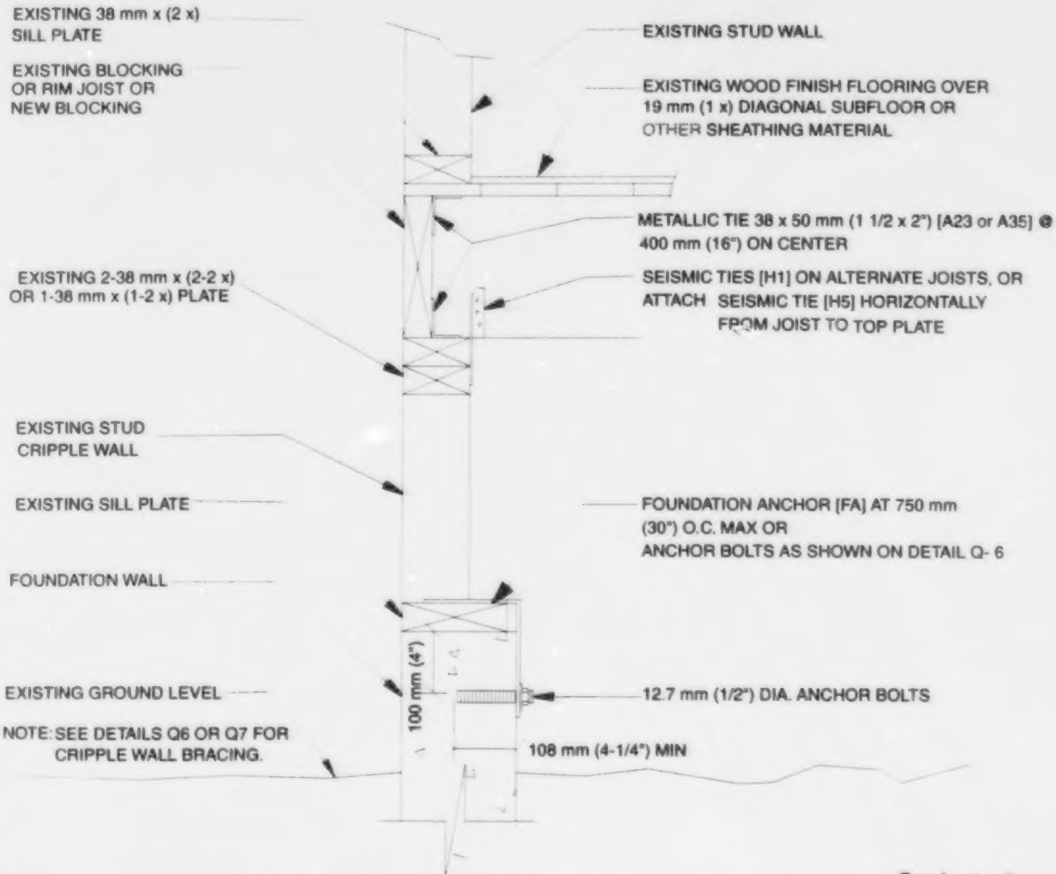
Q
1

CRIPPLE WALL DETAIL



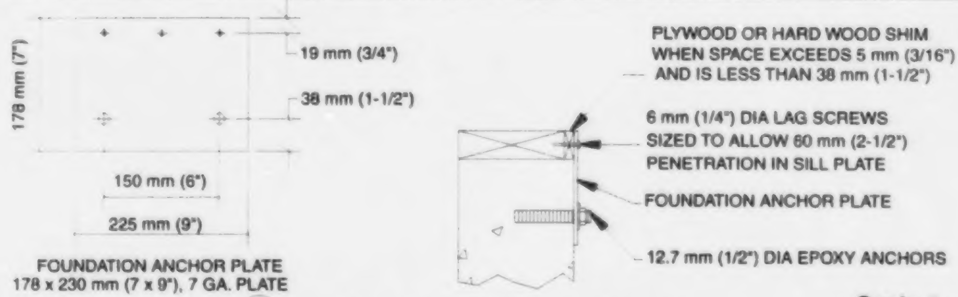
Scale 1:100

Q 2 CRIPPLE WALL BRACING LAYOUT - PLAN



A SILL TO BENT FOUNDATION ANCHOR PLATE

Scale 1 : 8

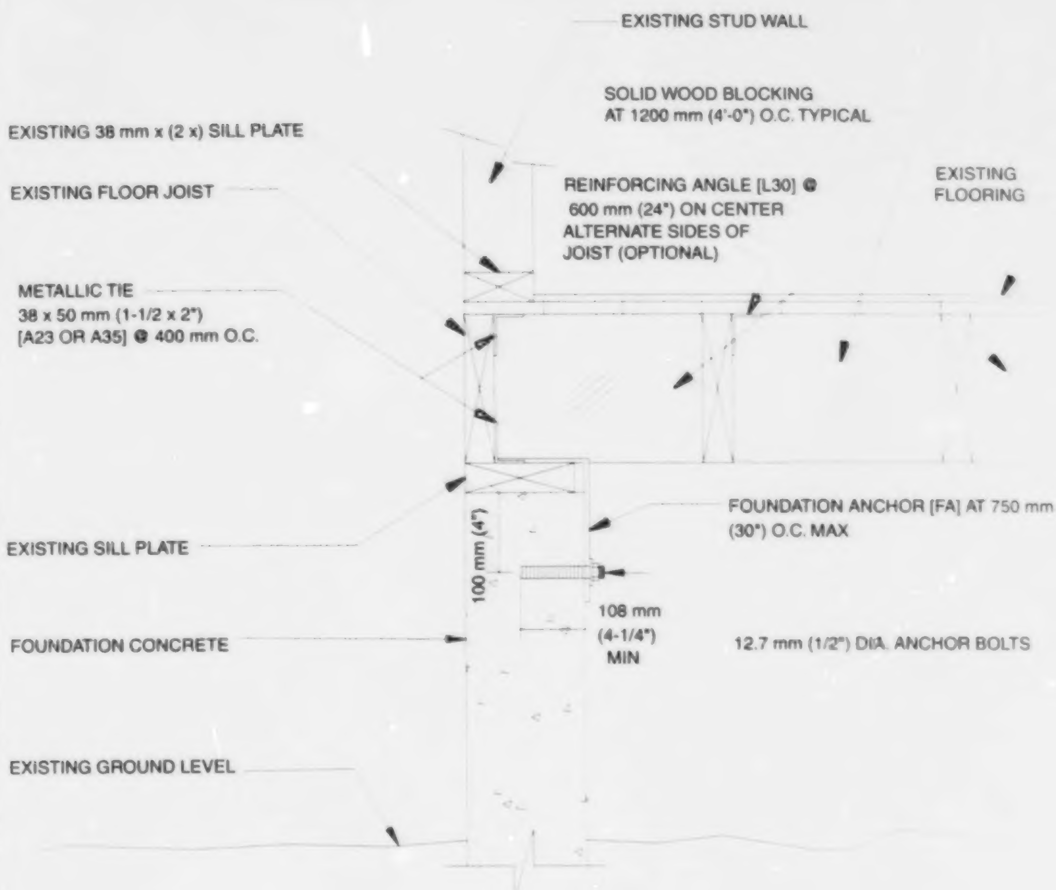


FOUNDATION ANCHOR PLATE
178 x 230 mm (7 x 9"), 7 GA. PLATE

B SILL TO FLAT FOUNDATION ANCHOR PLATE

Scale 1 : 8

Q 3 ALTERNATE SILL TO FOUNDATION CONNECTIONS



NOTES:

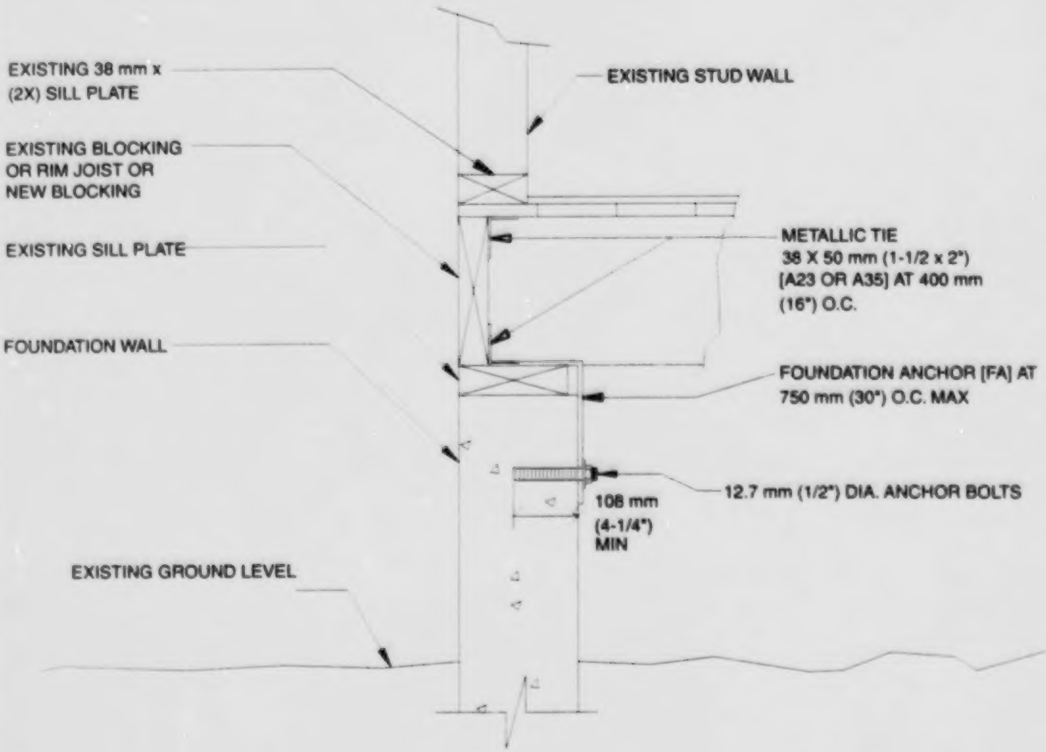
1. BLOCKING SHOWN IS MATERIAL SIMILAR IN SIZE TO EXISTING JOIST MATERIAL. SOLID BLOCKING TO BE TYPICALLY NOMINAL 38 mm x (2 x).

2. METAL CROSS-BRACING MAY BE AN ACCEPTABLE ALTERNATIVE TO SOLID BLOCKING.

Scale 1 : 8

Q
4

SILL PLATE BOLTING (NO CRIPPLE WALL)



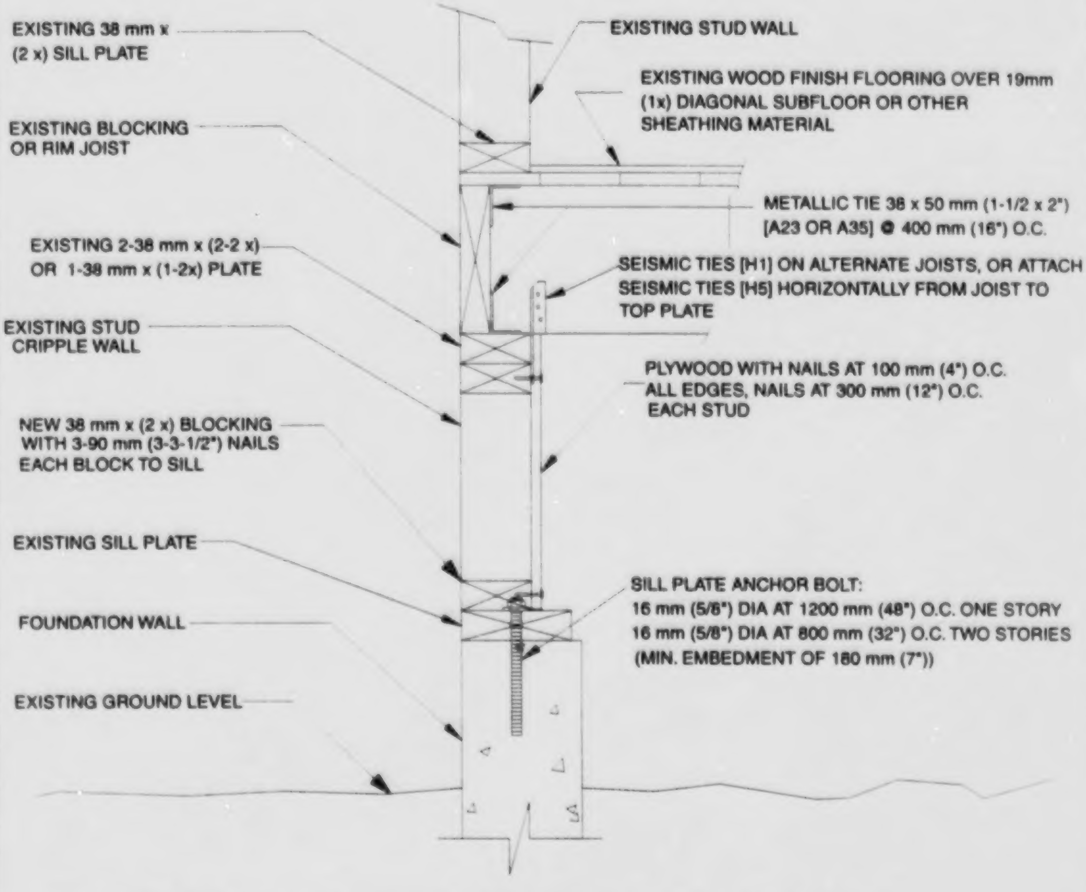
NOTES:

1. SEE DETAILS Q3, Q10 OR Q17 FOR PLATE AND CONNECTOR ARRANGEMENTS, AND REFER TO Q10 AND Q17 WHEN SPACE EXCEEDS 38 mm (1-1/2").

Scale 1 : 8

Q 5

SILL PLATE BOLTING (NO CRIPPLE WALL)

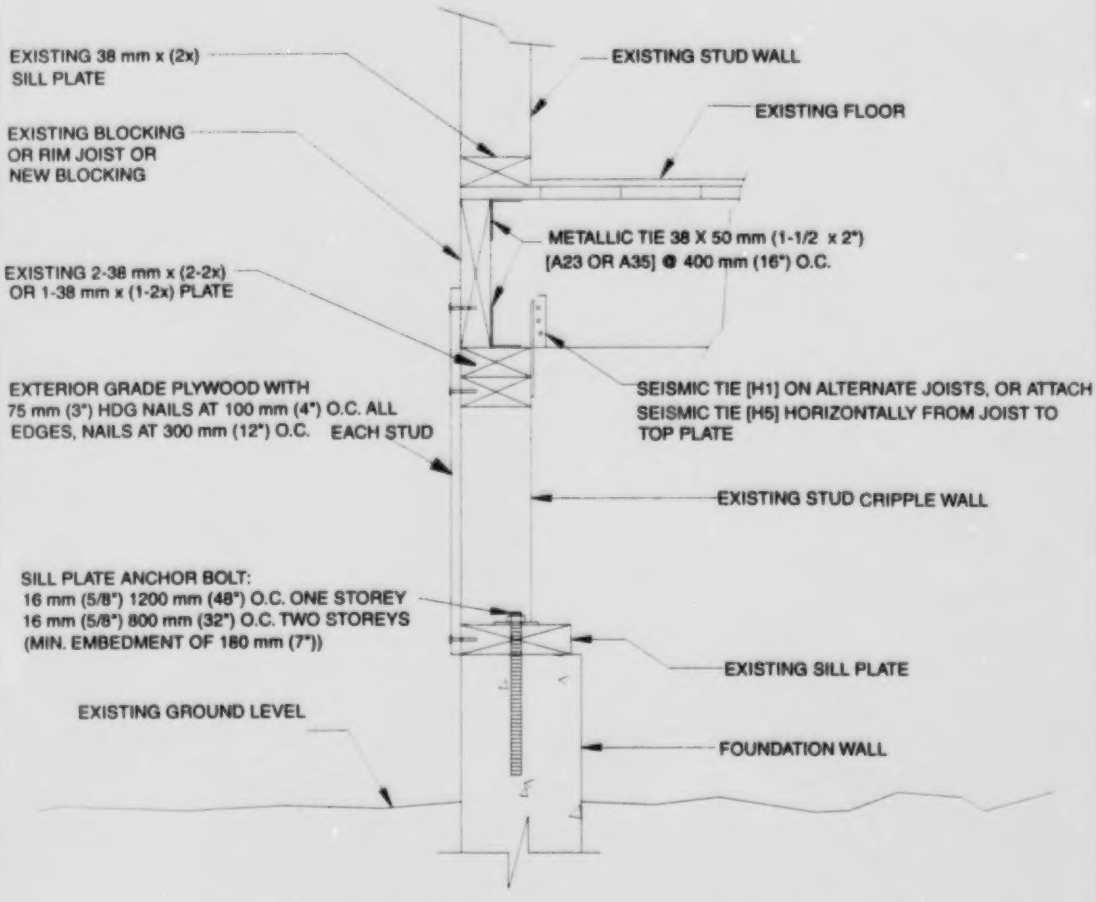


NOTE: WASHERS FOR SILL PLATE ANCHORS: 12.7 mm (1/2") DIA. = 50 x 50 x 5 mm (2 x 2 x 3/16")
16 mm (5/8") DIA. = 60 x 60 x 6 mm (2-1/2 x 2-1/2 x 1/4")

Scale 1 : 8

Q 6

CRIPPLE WALL BRACING @ INTERIOR FACE

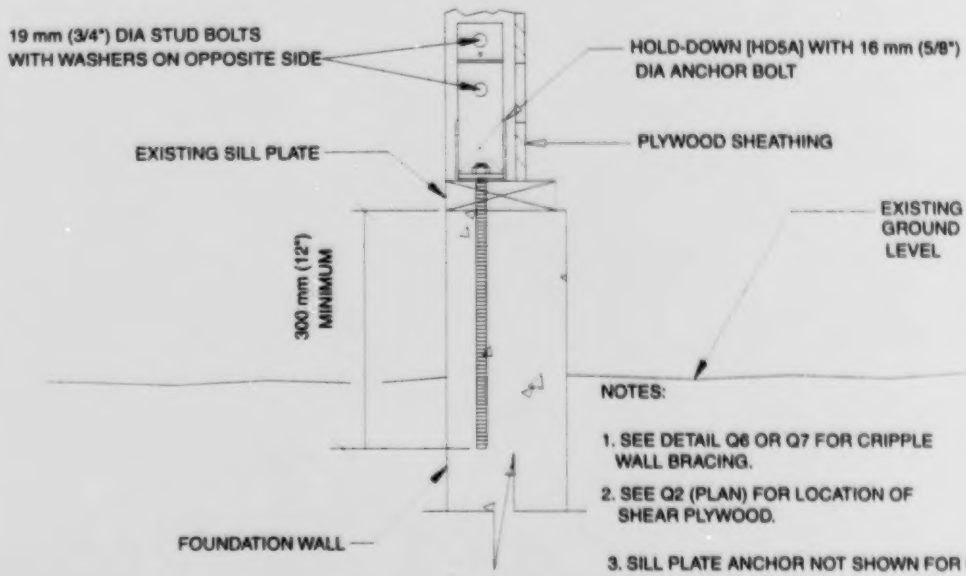


NOTE: WASHERS FOR SILL PLATE ANCHORS: 12.7 mm (1/2") DIA. = 50 x 50 x 5 mm (2 x 2 x 3/16")
16 mm (5/8") DIA. = 60 x 60 x 6 mm (2-1/2 x 2-1/2 x 1/4")

Scale 1 : 8

Q 7

CRIPPLE WALL BRACING @ EXTERIOR FACE



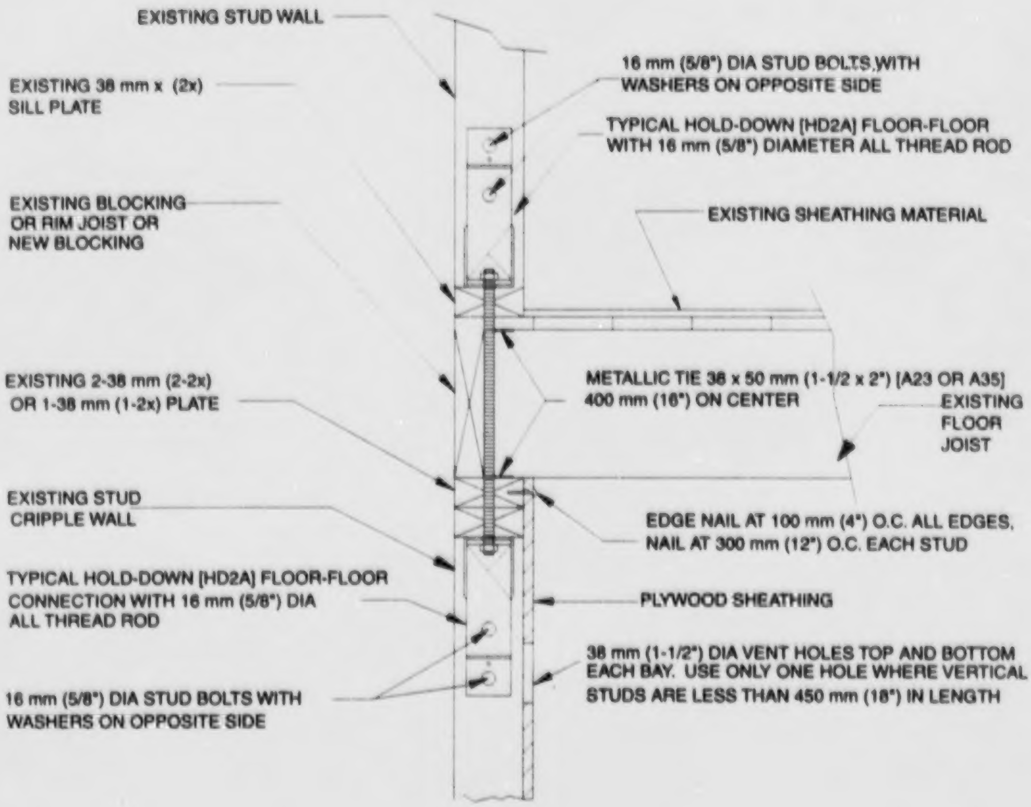
NOTES:

1. SEE DETAIL Q6 OR Q7 FOR CRIPPLE WALL BRACING.
2. SEE Q2 (PLAN) FOR LOCATION OF SHEAR PLYWOOD.
3. SILL PLATE ANCHOR NOT SHOWN FOR CLARITY

Scale 1 : 8

Q
8

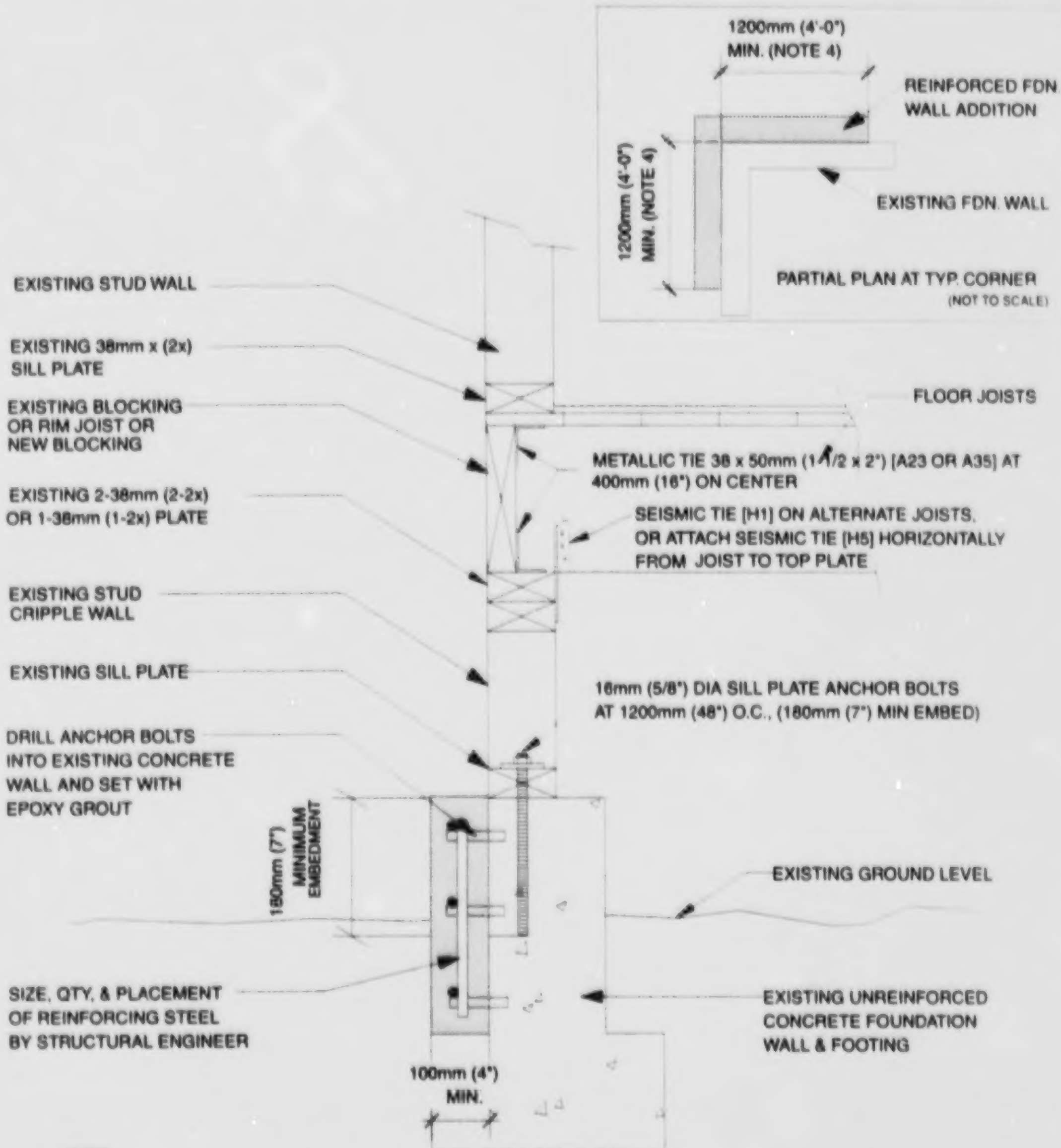
HOLD-DOWN ANCHOR BOLT (CRIPPLE WALL)



Scale 1 : 8

Q
9

FLOOR TO FLOOR TENSION TRANSFER



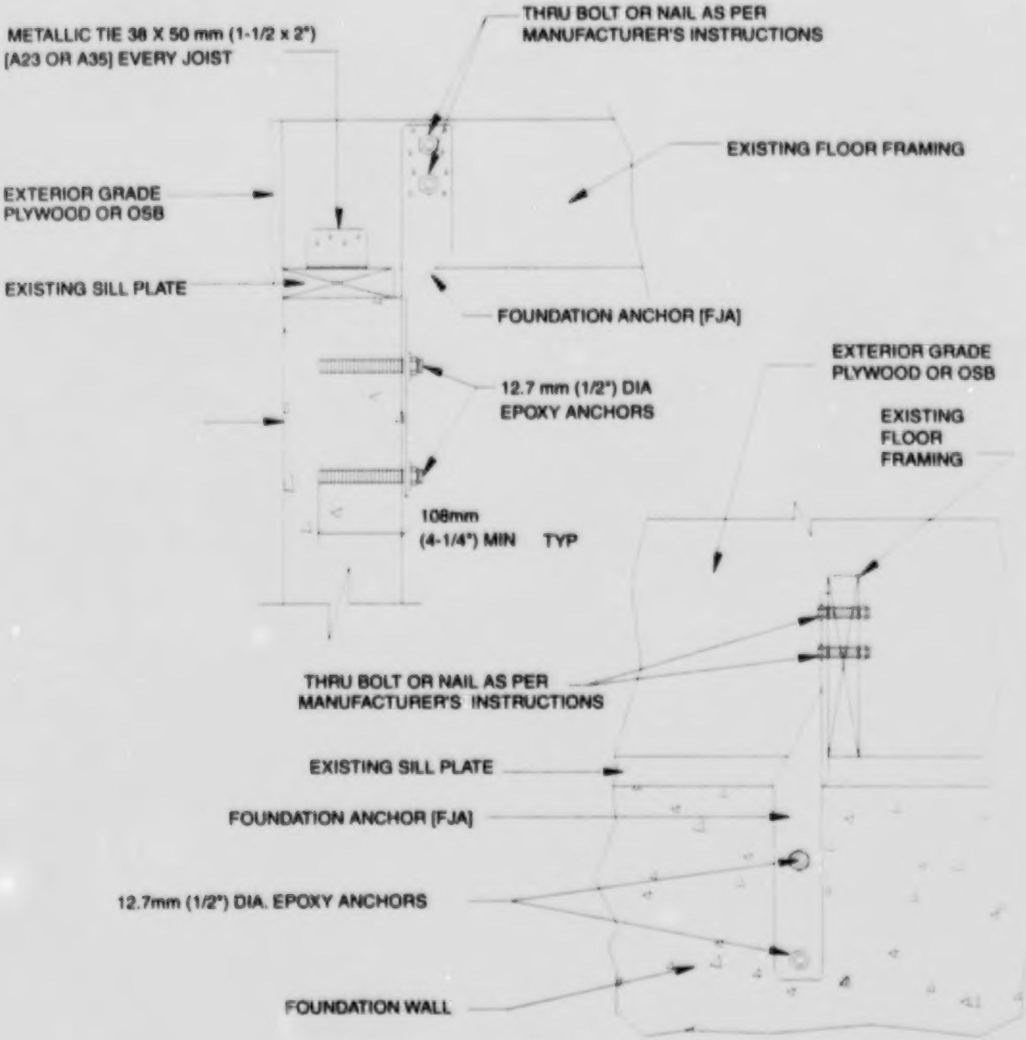
NOTES:

1. SEE DETAILS Q6, OR Q7 FOR CRIPPLE WALL BRACING
2. WASHERS FOR SILL PLATE ANCHORS: 12.7mm (1/2") DIA. = 50 x 50 x 5mm (2 x 2 x 3/16")
   16mm (5/8") DIA. = 60 x 60 x 6mm (2-1/2 x 2-1/2 x 1/4")
3. ADDITIONAL FOUNDATION WALL MAY BE SET ON INSIDE OF EXISTING FOUNDATION, IF PREFERRED.
4. THE MINIMUM LENGTH OF REINFORCED CORNERS SHOULD BE THE GREATER OF 1200mm (4'-0") OR THE LENGTH OF CALCULATED SHEAR WALL FOR THE CORNER.

Scale 1 : 8

Q
10

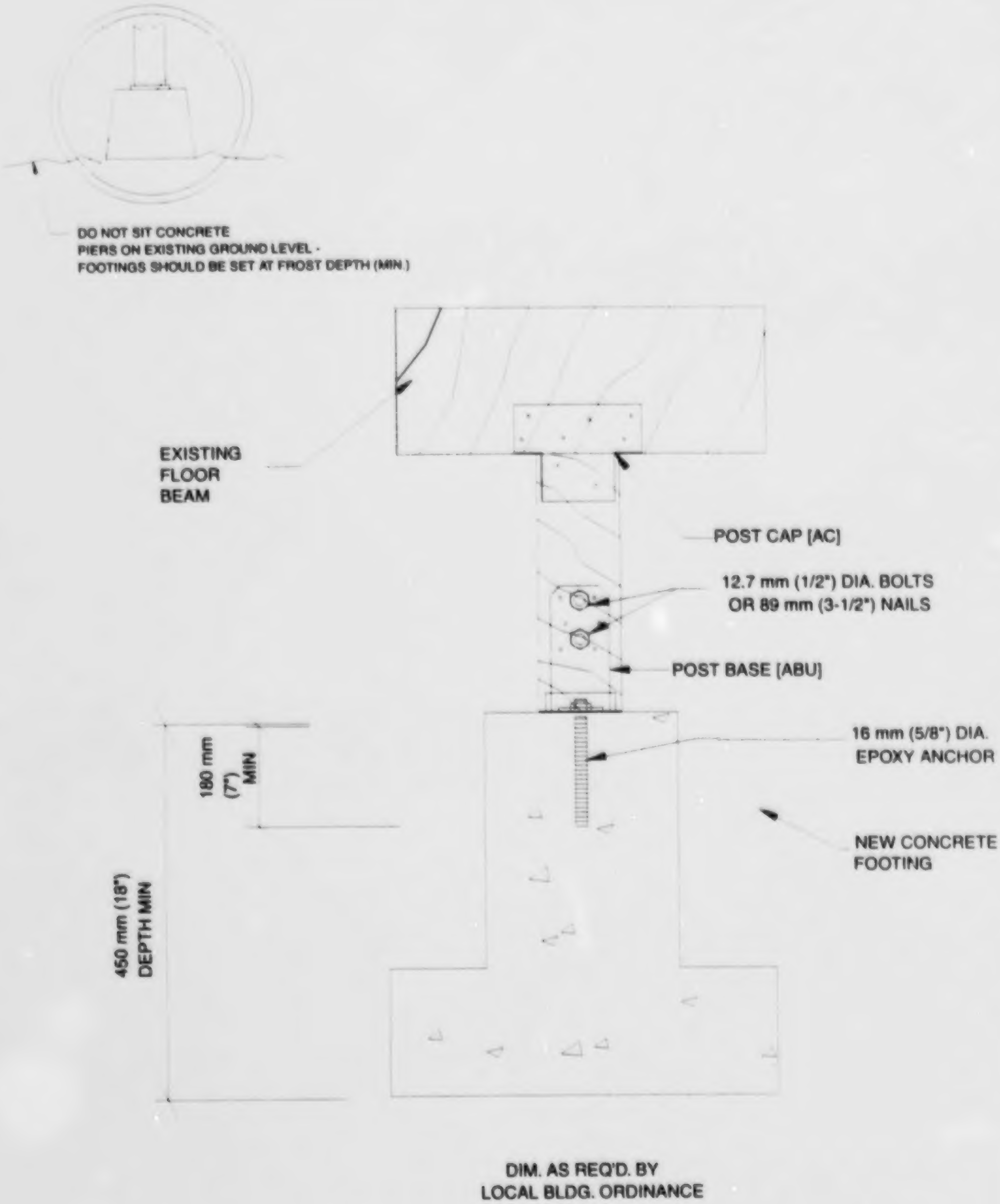
REINFORCING EXISTING CONCRETE FOUNDATION



Scale 1 : 8

Q
11

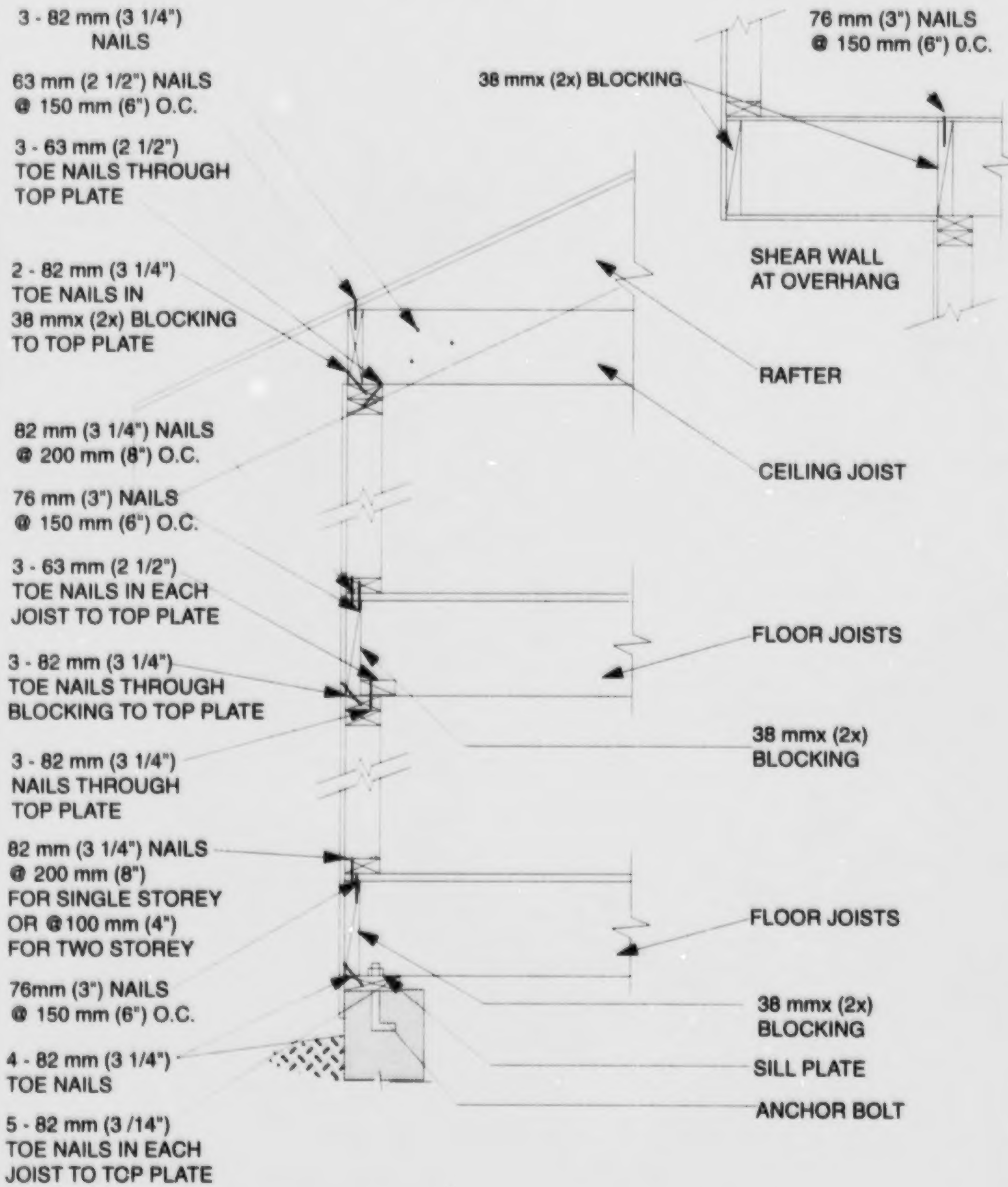
FOUNDATION ANCHOR DETAIL



Scale 1 : 8

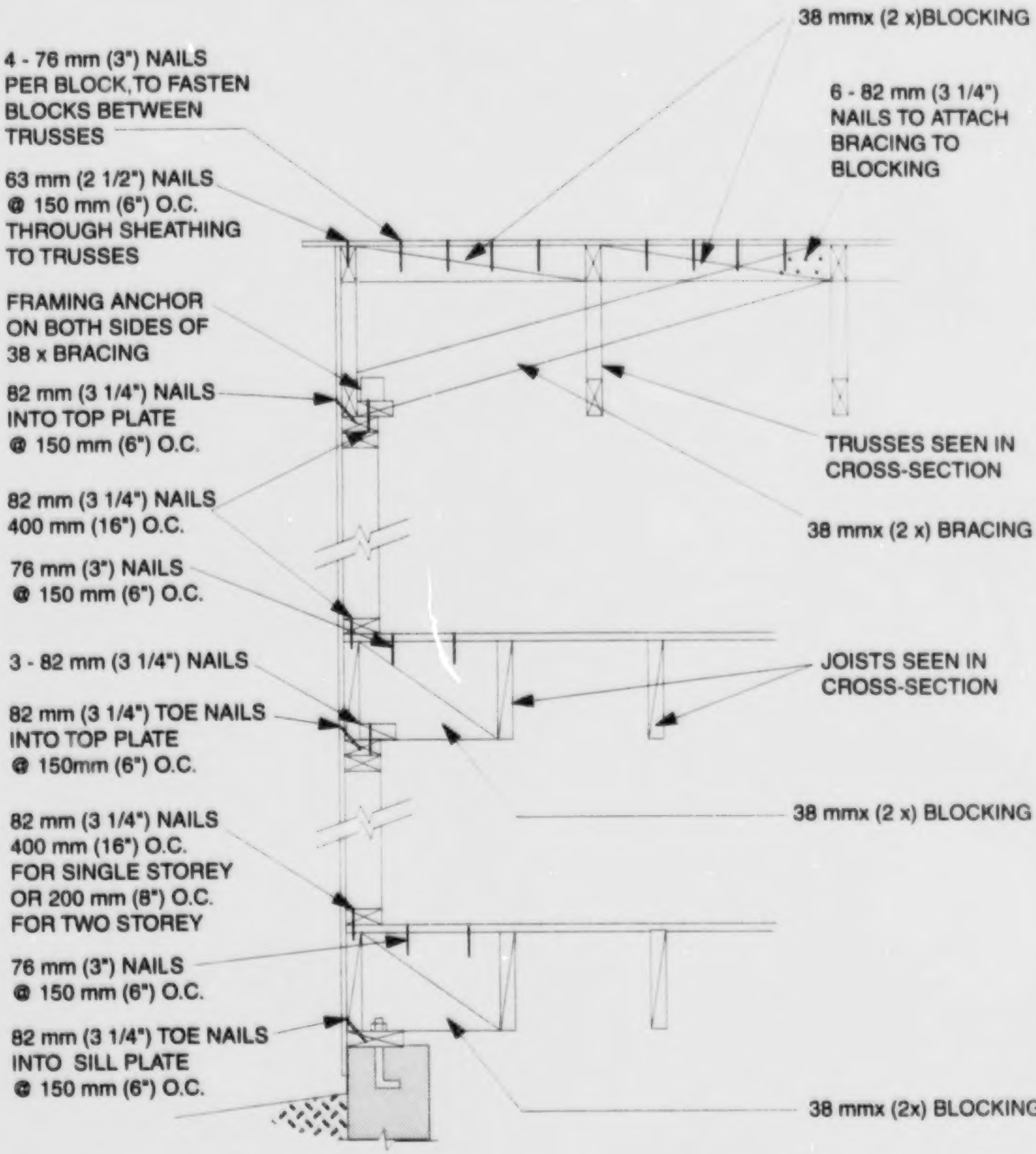
Q
12

NEW CONCRETE FOOTINGS



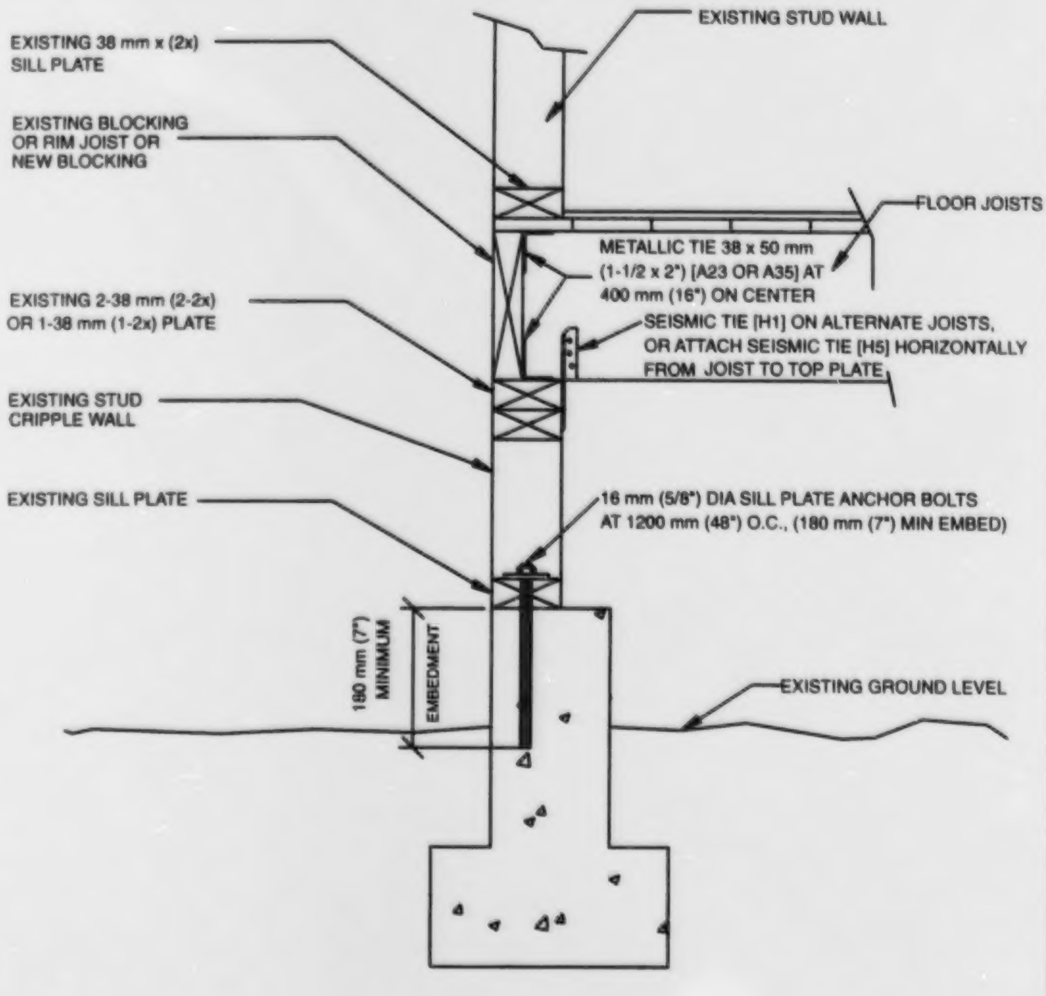
Q
13

RECOMMENDED SHEAR WALL FASTENING AT EXTERIOR WALLS - MINIMUM STANDARD



Q
14

RECOMMENDED SHEAR WALL FASTENING
AT EXTERIOR GABLE END WALLS - MINIMUM STANDARD



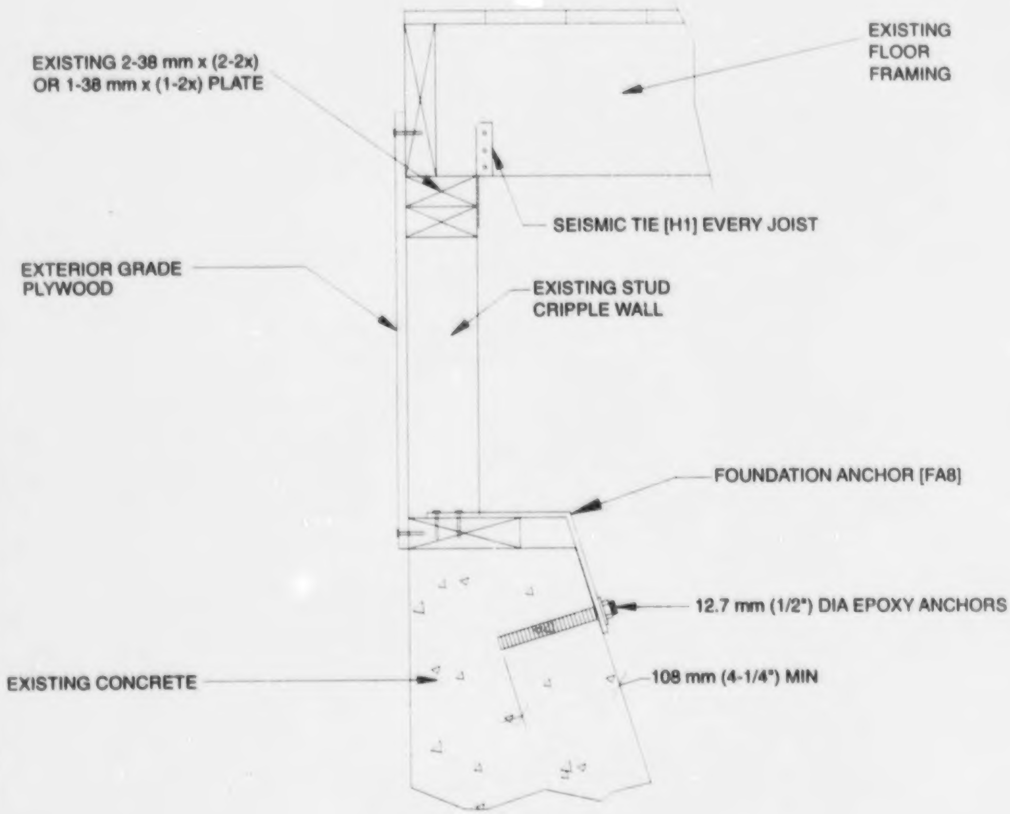
NOTES:

1. SEE DETAILS Q6, OR Q7 FOR CRIPPLE WALL BRACING
2. WASHERS FOR SILL PLATE ANCHORS: 12.7 mm (1/2") DIA. = 50 x 50 x 5 mm (2 x 2 x 3/16")
   16 mm (5/8") DIA. = 60 x 60 x 6 mm (2-1/2 x 2-1/2 x 1/4")

Scale 1 : 8

Q 15

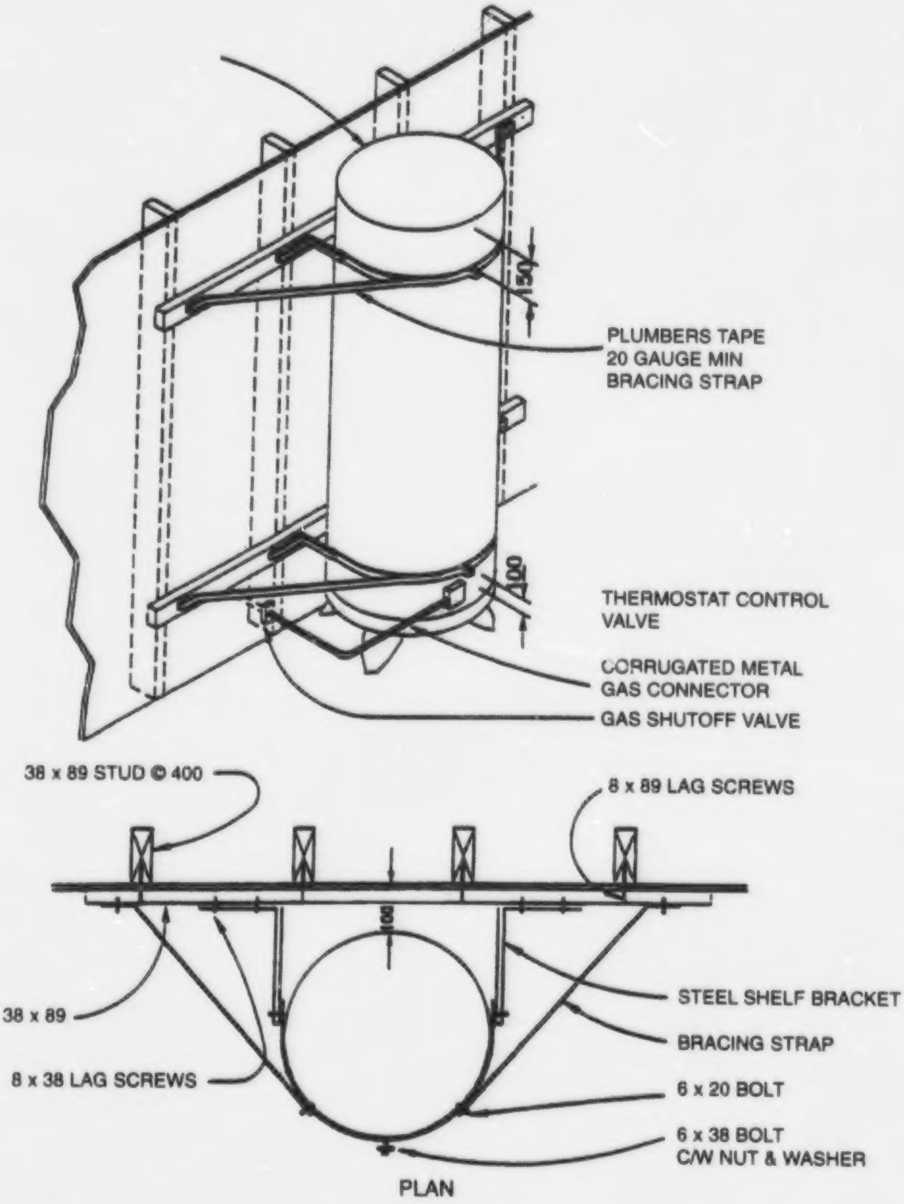
"NEW" CONCRETE FOUNDATION



Scale 1 : 8

Q
16

TRAPEZOIDAL FOOTING DETAIL



Q
17

WATER HEATER RESTRAINT DETAIL

DIRECTIONS FOR RESTRAINING WATER TANKS

1 DIRECTIONS FOR SECURING WATER TANK TO WALL:

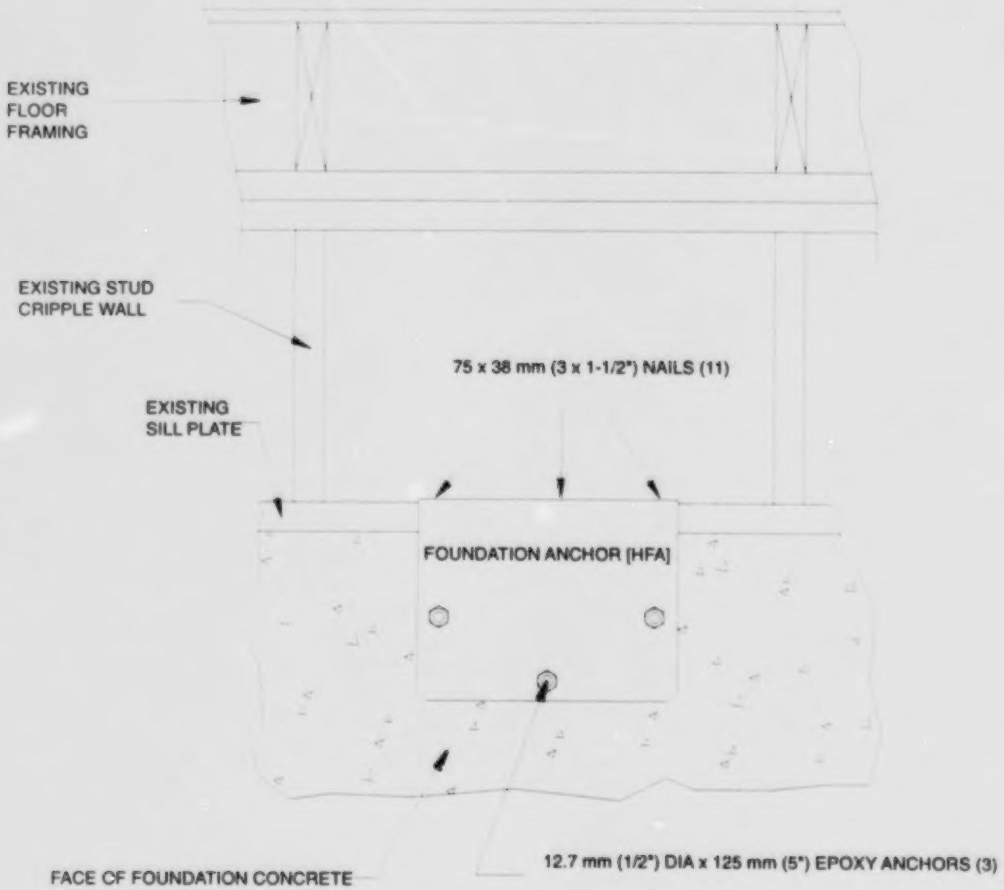
- USE AT LEAST 2 STRAPS, LOCATED APPROXIMATELY 150 mm (6") DOWN FROM THE TOP AND 450 mm (18") UP FROM THE BOTTOM.
- POSITION THE TANK CLOSE TO THE WALL.
- SOME ADJUSTMENT MAY BE NECESSARY TO AVOID WATER, GAS OR ELECTRICAL CONNECTIONS.
- IF THE WALL FOR ATTACHMENT IS WOOD FRAME, LOCATE THE STUDS IN THE WALL ON BOTH SIDES OF THE TANK. DRILL 5 mm (3/16") HOLES X 75 mm (3") DEEP THROUGH THE WALL FINISH MATERIAL AND INTO THE CENTRE OF THE STUDS. MEASURE AROUND THE TANK AND ADD 50 mm (2") TO THAT MEASUREMENT.
- CUT 2-40 mm (1-1/2") X 16 GAUGE (1.5 mm) METAL STRAPS TO THIS MEASURED LENGTH. BEND THE ENDS OF THE STRAPS OUTWARD 40 mm (1-1/2") TO AN APPROXIMATE RIGHT ANGLE. BEND THE STRAPS TO MATCH THE CONTOUR OF THE TANK.
- CUT 4 PIECES OF CONDUIT TO SPAN FROM THE HOLES DRILLED IN THE WALL TO THE MID-POINT ON EACH SIDE OF THE WATER HEATER. FLATTEN APPROX. 40 mm (1-1/2") AT EACH END OF THE PIECES OF CONDUIT AND DRILL 10 mm (3/8") HOLES THROUGH THE FLATTENED AREA (8 HOLES). BEND EACH END TO ABOUT 45 DEGREES. WRAP THE STRAPS AROUND THE HEATER AND INSERT AN 8 mm (5/16") X 32 mm (1-1/4") BOLT WITH WASHERS INTO THE BENT ENDS. TIGHTEN THE NUTS BY HAND. INSERT 8 mm (5/16") X 32 mm (1-1/4") BOLTS THROUGH THE STRAP FROM THE INSIDE AT THE MIDPOINT ON EACH SIDE OF THE WATER HEATER. ATTACH ONE END OF EACH TUBE STRUT TO A PROTRUDING BOLT, ADD A WASHER AND NUT AND TIGHTEN BY HAND. INSERT 8 mm (5/16") LAG SCREW IN THE OPPOSITE END OF EACH TUBE STRUT AND INSERT IN THE HOLE IN THE WALL STUD. TAP THE LAG SCREW GENTLY INTO THE HOLE TO START IT, THEN TIGHTEN WITH A WRENCH. ADJUST THE STRAPS AND TIGHTEN ALL NUTS SNUGLY, BUT NOT TOO TIGHT.

2 BOLTING TO A FLOOR: IF THE FLOOR IS CONCRETE, BE CAREFUL TO ALIGN WITH THE HOLES IN THE TANK. PLACE A LEAD EXPANSION SHIELD IN THE HOLES AND BOLT THE TANK TO THE SLAB.

3 BOLTING TO A CONCRETE OR MASONRY WALL: IF THE WALL IS CONCRETE, DRILL INTO IT. PLACE A LEAD EXPANSION SHIELD INTO EACH HOLE. INSERT A SCREW-EYE (6 mm [1/4"] OR THICKER) INTO THE SHIELDS. BRACE THE WATER HEATER WITH LIGHT STEEL CABLE WRAPPED AROUND THE TANK.

Q
17

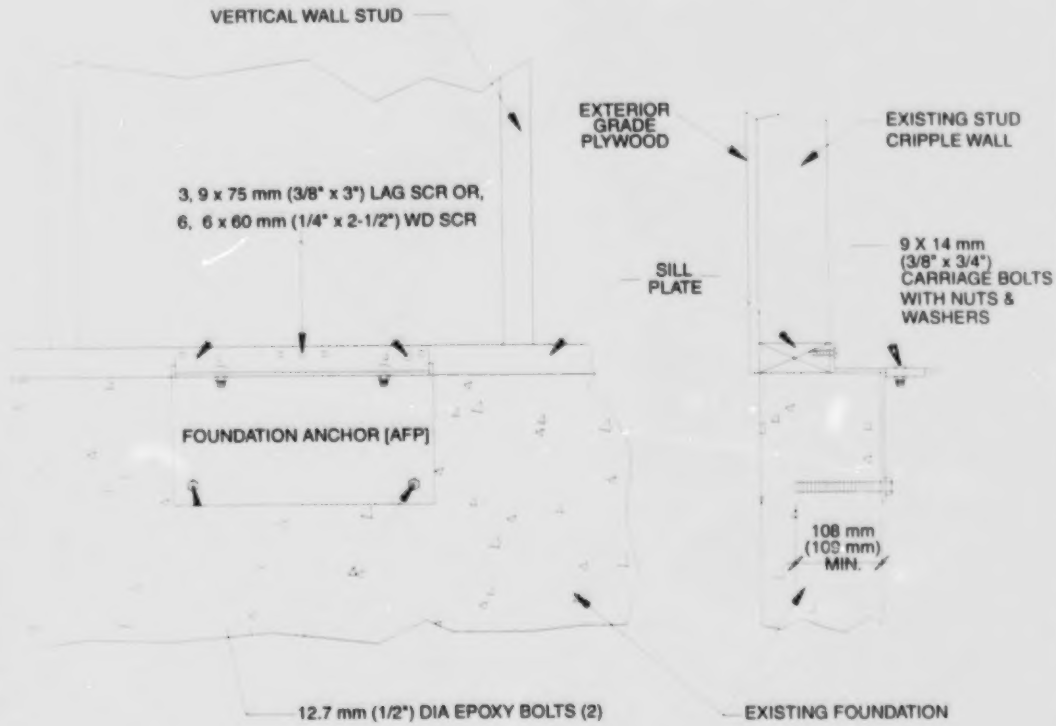
WATER HEATER RESTRAINT DETAIL



Scale 1 : 8

Q
18

TRAPEZOIDAL FOOTING DETAIL



NOTES:

1. TYPICAL APPLICATIONS OF THE ADJUSTABLE FOUNDATION PLATE INCLUDE:

   STEM OR SLOPED-FACE FOUNDATIONS
   TOP OR WET-SET SILL PLATE

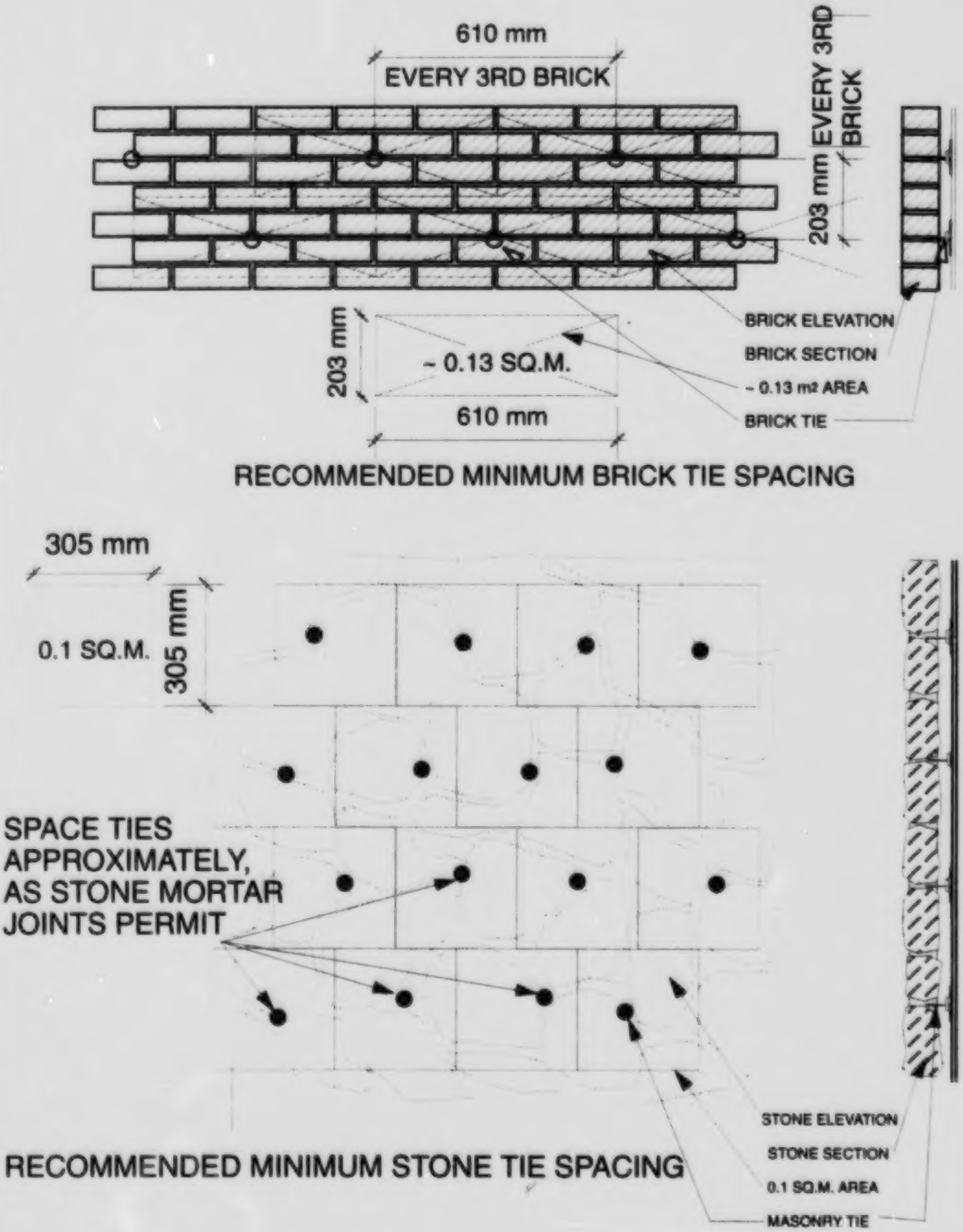
2. SPACE FOUNDATION ANCHORS [AFP's] AT 1800 mm (6'-0") ON CENTER.

3. THE FOUNDATION ANCHOR [AFP] WILL ACCOUNT FOR UP TO 60 mm (2-1/2") OF DIFFERENCE BETWEEN THE FOUNDATION THICKNESS AND THE SILL PLATE WIDTH.

Scale 1 : 8

Q 19

RECTANGULAR FOOTING DETAIL



Q 20

SCALE 1:15

RECOMMENDED BRICK AND STONE MASONRY TIE SPACING

Table C - 1:
Comparative Nail Sizes

LENGTH		penny	gauge	diam. of nail head
millimeters	inches	(U.S. measure)		(mm-in.)
25	1	2	15	4.4-11/64
32	1 1/4	3	A4	5.2-13/64
38	1 1/2	4	12 1/2	6.3-1/4
44	1 3/4	5	12 1/2	6.3-1/4
51	2	6	11 1/2	6.7-17/64
57	2 1/4	7	11 1/2	6.7-17/64
64	2 1/2	8	10 1/4	7.1-9/32
70	2 3/4	9	10 1/4	7.1-9/32
76	3	10	9	7.9-5/16
83	3 1/4	12	9	7.9-5/16
89	3 1/2	16	8	8.7-11/32
102	4	20	6	10.3-13/32
114	4 1/2	30	5	11.1-7/16
127	5	40	4	11.9-15/32
140	5 1/2	50	3	12.7-1/2
152	6	60	2	13.5-17/32

Table C - 2:
Comparative Gauges of Sheet and Screw Materials

GAUGE	FLAT MATERIAL		SCREW MATERIAL	
	mm	in.	mm	in.
000	9.5	375		
00	8.7	3437		
0	7.9	3125	1.5	060
1	7.1	2812	1.9	073
2	6.7	2656	2.2	086
3	6.1	2391	2.5	099
4	5.7	2242	2.8	112
5	5.3	2092	3.2	125
6	4.9	1943	3.5	138
7	4.6	1793	3.8	151
8	4.2	1644	4.2	164
9	3.8	1495	4.5	177
10	3.4	1345	4.8	190
11	3.0	1196	5.2	203
12	2.7	1046	5.5	216
13	2.3	0897		-
14	1.9	0747	6.1	242
15	1.7	0673		-
16	1.5	0598	6.8	268
17	1.4	0538		-
18	1.2	0478	7.5	294
19	1.1	0418		-
20	0.9	0359	8.1	320
21	0.8	0329		-
22	0.76	0299		-
23	0.68	0269		-
24	0.60	0239	9.4	372
25	0.53	0209		-
26	0.45	0179		-
27	0.42	0164		-
28	0.38	0149		-
29	0.34	0135		-
30	0.30	0120	11.4	450

APPENDIX D

SOURCES FOR SEISMIC PRODUCTS AND SERVICES

APPENDIX D
SOURCES FOR SEISMIC PRODUCTS AND SERVICES

The following companies market seismic-related products. The list is by no means exhaustive. It simply represents sources of products of which the authors became aware during their research. No guarantee or warranty is offered or implied by including a company or product on this list. Neither the authors nor CMHC received any compensation or other consideration for including a company on this list.

Table D - 1:
List of Companies

COMPANY/ Contact information	PRODUCTS/SERVICES AVAILABLE
BC Gas Utility Ltd. 4180 Lougheed Highway Burnaby, B.C. Tel: 604 293-8722 Fax: 604 293-8763 Contact: Greg Bennett Emergency Preparedness Coordinator	
Braidner Survival Kits (1990) Ltd. #101-1001 W. Broadway Unit 340 Vancouver, B.C. V6H 4E4 Tel: 604 254-0455 Fax: 604 254-8685 Internet: http://www survivalkits.com Contact: Roberta Niemann	• Earthquake survival kits
Courage Distributing Inc. Head Office: 2170 Dunwin Dr. #44 Mississauga, Ontario L5L 5M8 Tel: 905 607-4950 Fax: 905 607-4954 Vancouver office: 2560 Simpson Road #170 Richmond, B.C. V6X 2P9 Tel: 604 278-5058 Toll free 1 800 268-7243 Fax: 604 278-5069 Contact: James Milligan	• Security films for glazing
DUR-O-WAL Inc. Corporate and Sales Headquarters 3115 North Wilke Road, Suite A Arlington Heights, IL 60004 Tel: 847 577-6400 Fax: 847 577-6418 Technical Assistance & Sales Toll Free 1 800 323-0090 Canada **DUR-O-WALL, Ltd** 1750 Bonhill Road Mississauga, Ontario L5T 1C8 Tel: 905 670-4470 Fax: 905 670-4474	• Flexible wall stabilizing anchors for masonry • Masonry replacement anchors for facade stabilization • Seismic veneer anchors and compatible reinforcing systems

Steels Industrial Products Ltd Corporate Office 15050 - 54A Avenue Surrey, British Columbia V3S 8E7 Tel: 604 576-3111 Fax: 604 576-0111 Contact Don Unwin Tel: 604 291-7321	
Earthquake Preparedness Society 7981 168th Ave. N.E. Redmond, Washington 98052 Tel: 206 556-0911 Fax: 206 556-0734 Contact: Vaughan Mason, Manager	• Distributors for a wide variety of earthquake preparedness kits, books and video tapes, water supplies, sanitation supplies, food, fire safety equipment, etc.
Fine Arts Conservation Laboratories P.O. Box 23557 Santa Barbara, California 93121 Tel: 805 564-3438 Contact: Scott M. Haskins, Conservator of Fine Arts	• Post-disaster recovery of damaged fine art
First Aid & Survival Technologies (F.A.S.T.) 1687 Cliveden Ave. W. Delta, B.C. V3M 6V5 Tel: 604 540-8300 Fax : 604 540-8301 Contact: Ingrid Mravunac	• Manufacturers of a variety of emergency preparedness kits for work sites, office buildings, schools and homes. Kits developed in conjunction with B.C. Hydro
Four Seasons Window Films Inc. 73-3031 Williams Road Richmond, B.C. V7E 4E9 Tel: 604 272-1910 Contact: Stewart W. Beebe	• Security films for glazing
Geological Survey of Canada National Earthquake Hazard Program Eastern Canada 1 Observatory Crescent Ottawa, Ontario K1A 0Y3 Tel: 613 995-5548 (English) Tel: 613 995-0600 (French) Fax 613 992-8836 Western Canada 9860 West Saanich Road Sidney, B.C. V8L 4B2 Tel: 604 363-6450 Fax: 604 363-6565 or Map and Publication Sales 101-605 Robson St. Vancouver, B.C. V6B 5J3 Tel: 604 666-0271 Internet http://www.seismo.nrcan.gc.ca	• Operates Canadian National Seismograph Network • Monitors earthquake activity • Publishes Seismicity Map of Canada • Publishes "Geofacts," pamphlets for general distribution; • Publishes Geological Survey of Canada research • Performs site-specific hazard calculations for $60+taxes.
International Hazard Response Systems Inc. Champlain Mall, P.O. Box 42014 3200 East 54th Ave. Vancouver, B.C. V5S 4R5 Tel: 604 322-8798 Toll free 1 888 776-8228 Fax: 604 322-9182 Contact: Ken D.B. Lee Vice President of Operations	• Emergency preparedness kits and products

Mennonite Central Committee 31414 Marshall Road, P.O. Box 2460 Abbotsford, B.C. V2T 4X3 Tel: 604 850-6608 Fax: 604 850-2634 Contact: Kewal Uppa	• Emergency preparedness kits assembled in non-profit environment
Safe Pak 1638 Kebet Way Port Coquitlam, B.C. V3C 5M5 Tel: 604 942-8830 Toll free 1 800 665-7233 Fax: 1 800 663-8666 Contact: Liesa Hoodekoff Sales Representative	• Emergency preparedness products
Seismic Safety Products, Inc. 432 Olds Station Road Wenatchee, Washington 98801 Tel: 509 664-1990 Toll free 1 800 948-3782 Fax: 509 663-7811 Contact: Ed Fields, Sales Manager	• Distributors of the Northridge Valve, an ingenious gas shut off valve
Shake & Quake Fasteners Ltd 839 - 164 Street Surrey, British Columbia V4A 4Y4 Tel: 604 536-0733 Fax: 604 536-3491 Contact: W.P. Koehler	• Furniture restraint devices
S[illegible]pson Strong-Tie Company, Inc 1450 Doolittle Drive San Leandro, California 94577 Tel: 800 999-5099 or 510 562-7775 Fax: 510 632-8925 Contact: Reinhard Pekarek	• Complete range of metal connectors for seismic use for residential construction. Available through many large hardware or lumber stores and by order through smaller outlets.
TerraFirm Inc. 3970 West 17th Avenue, Vancouver, British Columbia, Canada V6S 1A5 Tel/Fax: 604 224-3369 e-mail: terrafirm@mindlink.bc.ca Contact: Jay Lewis, President	• Specialist in earthquake prepareness for family and home. Provides and installs appliance securing, furniture fastening, window safety film, survival equipment. Consulting for structural re-engineering, and emergency planning.
The Canadian Red Cross Society **Health Promotion Services** Fraser Pacific Region Tel: 604 879-7551 Fax: 604 872-7126 Contact: Theresia On Program Assistant or Barry Growe Program Co-ordinator	• Emergency preparedness programs and post-disaster planning
U.S. Army Corps of Engineers **Earthquake Preparedness Center of Expertise** 333 Market St. San Francisco, California 94105-2195 Tel: 415 977-8334 Contact: Richard Cook	• Earthquake preparedness planning and publications

Westcoast Seismic Protection Co. 439 McLean Drive Vancouver, British Columbia V5L 3M5 Tel: 604 255-0140 Fax: 604 255-1054 Contact: John O'Sullivan	• Seismic gas shut off valves
Worksafe Technologies Pacific Coast Rep: Counter Quake Services Inc. 1279 Tattersall Drive Victoria, B.C. V8P 1Z5 Tel: 604 383-4400 Fax: 604 381-1295 Contact: Robert Laundy Headquarters: 25133 Avenue Tibbitts, Bldg. F Valencia, California 91355 Tel: 805 257-2527 Fax: 805 257-2547 Contact: Don Hubbard President	• Seismic and environmental safety products and services, largely focused on products to secure contents down to prevent movement in an earthquake.
WPS Emergency Planning P.O. Box 638 Fort Langley, B.C. V1M 2S1 Tel: 604 888-6460 Fax: 604 888-7127 Contact: Rob Ingram Director of Marketing	• Emergency preparedness plans

APPENDIX E

TIPS FOR WORKING WITH CONTRACTORS

APPENDIX E
TIPS FOR WORKING WITH CONTRACTORS

The following comments are offered based on the authors' experience.

DECIDING TO MAKE REPAIRS

- Do not rush into repairs, no matter how badly they are needed. A little extra time and attention at this stage can pay dividends.
- Remember, home improvement and repair projects provide opportunities for the unscrupulous.
- Do not be victimized by someone making a door-to-door presentation, offering to do repair jobs or home improvement on-the-spot, but requiring a cash deposit.

SELECTING A CONTRACTOR

- Do not hire the first contractor who comes along.
- If a person says they are representing a contractor, call the contractor and ask if the person is authorized to act on their behalf.
- If three or more types of work are required, your project should probably be done by a general building contractor.
- Keep in mind that you will be opening your house to the contractor for a period of weeks or months. Look for someone you want in and around the house on an extended basis.
- Get at least three bids and ask for references about work the contractor has completed in the area.

VERIFYING THE CONTRACTOR'S QUALIFICATIONS

- Even on the smallest job, you must get proof that the person you are dealing with has a business licence as well as a trade licence in the trade involved in the proposed work.
- Call Workers' Compensation Board to ensure the contractor has coverage and is in good standing, that is, has been paying assessments.
- Ask the contractor for insurance references, and call to check that the contractor has liability and property damage insurance coverage.
- Ask to see the contractor's business license and GST Number. Ask to see some additional form of identification so you know with whom you are dealing.
- Contact the people provided as references and ask questions that will help you decide if the contractor will satisfy your needs. This takes time, but saves money and aggravation in the long run. Since you will not likely be able to hold back monies from the contractor during any warranty period (typically one year after completion of the work), make a special effort to check post-completion performance, remedying of defects, etc.

SIGNING THE CONTRACT AND MAKING PAYMENTS

- Do not pay cash, do not let the payments get ahead of the work completed, and do not pay the full cost of the job up-front. A deposit may be appropriate, especially for a smaller project with a small contractor, in order to allow the contractor to purchase necessary materials and supplies.
- If your contract includes any work on a time basis, check work progress daily and keep a simple diary in which you note work accomplished on a given day, number and type of workers involved, etc. If you are not happy with progress, bring your concerns up with the contractor immediately.
- Require a written contract, and do not sign until you fully understand the terms. Remember, if it is in the contract, you can expect to have it done. If it is not there, even with a verbal promise, you may not get what you think you are paying for. Include everything you have agreed upon: work to be done; start date and finish date; materials to be

used, warranties by the contractor, and financial terms of cost and payment arrangements. Specify that the contractor is responsible for obtaining all permits, and lien releases from all sub-contractors and material suppliers. Sign only the complete contract and retain a copy for your records.

- The Canadian Home Builders' Association of B.C. has standard form estimates and contracts that are for sale for a few dollars per copy. Require the contractor to use these forms - inapplicable clauses can be easily struck out.

INSPECTING THE WORK

- Ensure that your contractor has building permits before work starts. Most renovation work requires a building permit as well as trade permits for any electrical, gas, plumbing, mechanical or sprinkler work. Take copies of all of these permits. It is a good idea for the contractor to keep all of the permits on site. A good idea is to place them all, together with the municipally approved drawings, in a clear plastic bag (a large freezer bag will do) and hang them in a convenient location where the work is going on.
- Check work progress daily. Take photographs of work in progress, especially things that will be covered up later on (plumbing and electrical rough-in, framing, insulation, etc.). This will likely be your only record of the "as-built" conditions.
- Make sure the contractor calls for all required municipal inspections. Usually these include all work before it is covered up, as well as a final inspection at the end.
- At the end of the project, do your own detailed inspection. Municipal inspectors are not usually concerned with the details of finishing and similar quality concerns. If you are unhappy with the quality of anything, be up front about it. If work is not completed or remedied to your satisfaction, hold back twice as much money as the contractor estimates it will cost to fix, until it is fixed to your satisfaction (The twice-as-much suggestion covers the extra cost of getting another worker to come in and complete the work, if the first worker or contractor refuses and leaves the job. This is normal practice with large projects as well.)
- In addition to any amounts to cover remedial work, hold back 10% of the overall cost of the work for 41 days (this is the time period in B.C.: in other jurisdictions, consult the local building authority for the equivalent time period) after the completion date. Mark the 41st day on your calendar, and on that day contact your land registry office (known as the land titles office in some jurisdictions) and check if any liens have been filed. A lien is a charge on the property that can be placed by any contractor, individual worker or supplier to cover alleged nonpayment. A lien is easy to place and may require legal action on your part to remove, if it is unjustified. Liens must be discharged before a property can be conveyed (i.e., sold). Do not release the 10 per cent hold back monies until all liens have been removed, either by the contractor paying his bills or by you or your lawyer negotiating settlements as appropriate.

WARRANTIES AND GUARANTEES

- Most contracts include a one year warranty, during which time the contractor is obliged to make good any defects that were not apparent at completion time, for example drywall cracks, settlement, leaks and defective products. If apparent to you, contact the person with whom you signed the contract (not the workers or subcontractors) immediately, explain the problem and get a commitment for repair or replacement.
- If the contractor refuses to make good the warranty, first try verbal convincing and include a threat to report the inaction to the local building officials and municipal licensing authorities, if necessary. Where the contractor still refuses to make good, and the threats don't work, advise the contractor in writing by double-registered mail or courier that he/she has five working days to make good, or you will employ someone else and seek recompense in the courts. If this elicits no resolution, and you are confident in your

position, employ another to repair the defects and expect to have to go to small claims court to recover your losses. It may be worthwhile before taking this action to ask a third party, such as an architect, to examine the problem and your contracts and to advise you as to whether you have a cause, and also how best to make good the defects.

- There are almost always small defects that become apparent in the first year—the most common is drywall cracking due to wood framing shrinkage. If observed defects are minor and you wish the contractor to make good, wait until the 11th month of the warranty period, then contact the contractor, describe the defects and make an appointment for inspection and remedial work. A good contractor will review the problems on site, agree on the spot which problems he/she will remedy and either do the work immediately or arrange an appointment to carry out the work.

APPENDIX F

CASE STUDY

APPENDIX F
CASE STUDY

In order to assist the *Guide* user to evaluate a specific house, a case study of an existing house requiring seismic upgrading has been completed.

The study house is in Vancouver, British Columbia (seismic zone 4), on a typical urban lot of 10 m x 36 m (33' x 120'). It is a two storey plus high basement house and has many of the problems highlighted in the *Guide*, including:

- siting issues in relation to services and neighbours;
- a cripple wall in the basement that is neither braced nor bolted to the unreinforced concrete foundations;
- a majority of interior walls that do not line up from floor to floor;
- an old masonry fireplace and chimney that protrudes about 3 m above the adjacent roof, presenting a significant collapse hazard;
- interior plaster finishes;
- an unrestrained hot water tank and gas fired furnace, both with rigid service connections and connected to a central, unreinforced masonry flue through the centre of the house;
- a rear deck built on old, suspect piers, without cross bracing.

As recommended in the *Guide*, the evaluation has been carried out as follows:

- The house was inspected using Checklists A through D, and the relevant portions are included here.
- Basic floor plans and elevations of the house were drawn, and photos taken, for the purpose of more accurately describing the conditions.
- A summary of risks and a master upgrade plan of action was developed, using the forms included in Appendix I.

Note that imperial measures have been used, as these measures most accurately describe the materials used in the construction of the house in 1939.

INSPECTION OF THE HOUSE

As illustrated in Figure F-1 below, the house, which was built in 1939, has its main floor approximately 1.4 m (4.5 ft) above adjacent grade. The site is essentially flat and in a well drained area where city hall advises soil conditions are excellent—compacted gravelly and silty subsoil atop rock.

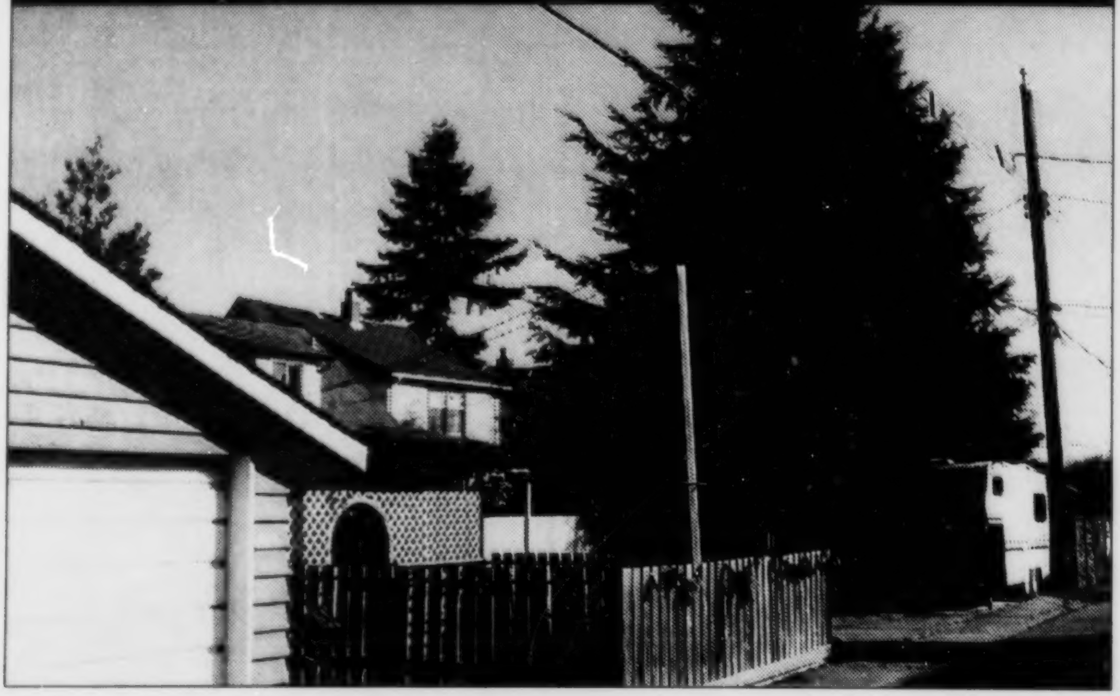
At the north (street) side, the house is flanked by two neighbours with lower heights.

Figure F - 1:
Street Elevation of the Case Study House

The rear of the house has a recent vintage deck structure attached at the main floor level. The roof overhang over the french doors is the remains of an original rear porch. To the left of the french doors, the kitchen is cantilevered out approximately 0.6 m (2 ft) from the line of the walls above and below.

Figure F - 2:
The Rear (Lane) Elevation of the Case Study House

Figure F - 3:
Collapse Hazards - Hydro Pole and Neighbouring Tall Trees



EXAMINING THE PROPERTY

Using Checklist A, the property conditions were analysed and documented.

There are tall trees in the neighbour's back yard that could be a collapse hazard onto the the subject property, as well as a hydro utility pole. This suggests the rear of the property should not be considered as an emergency egress route.

The house also has an old garage on the lane, which would also likely collapse in an earthquake, impeding egress in the lane direction.

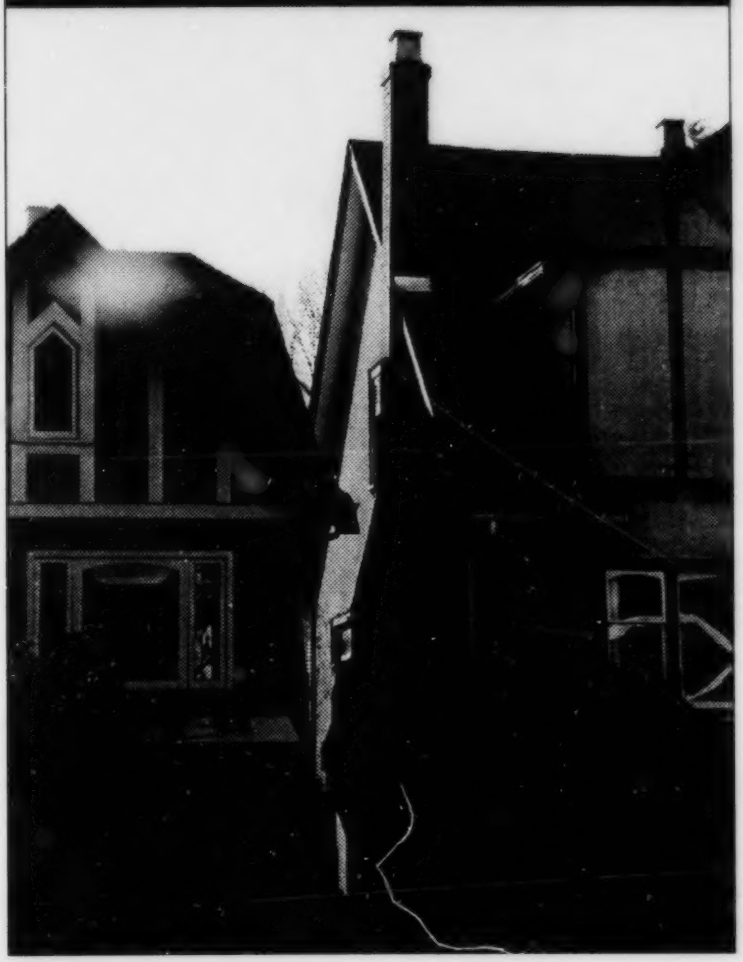
Figure F - 4:
Garage as Collapse Hazard

The house is quite close to its neighbours, as is typical of that vintage construction. Separations are approximately 1.8 m (6 ft). This results in at least two hazards.

Figure F - 5:
Neighbour's Chimney as a Collapse Hazard

First the old masonry chimney on the house to the west will likely collapse in an earthquake, possibly damaging the subject house. The chimney is close to the front entry of the subject house, which underlines the dictum that one should not leave a house during an earthquake.

Figure F - 6:
Collapse Hazard - Masonry Chimney at East (Left) Side of Subject House



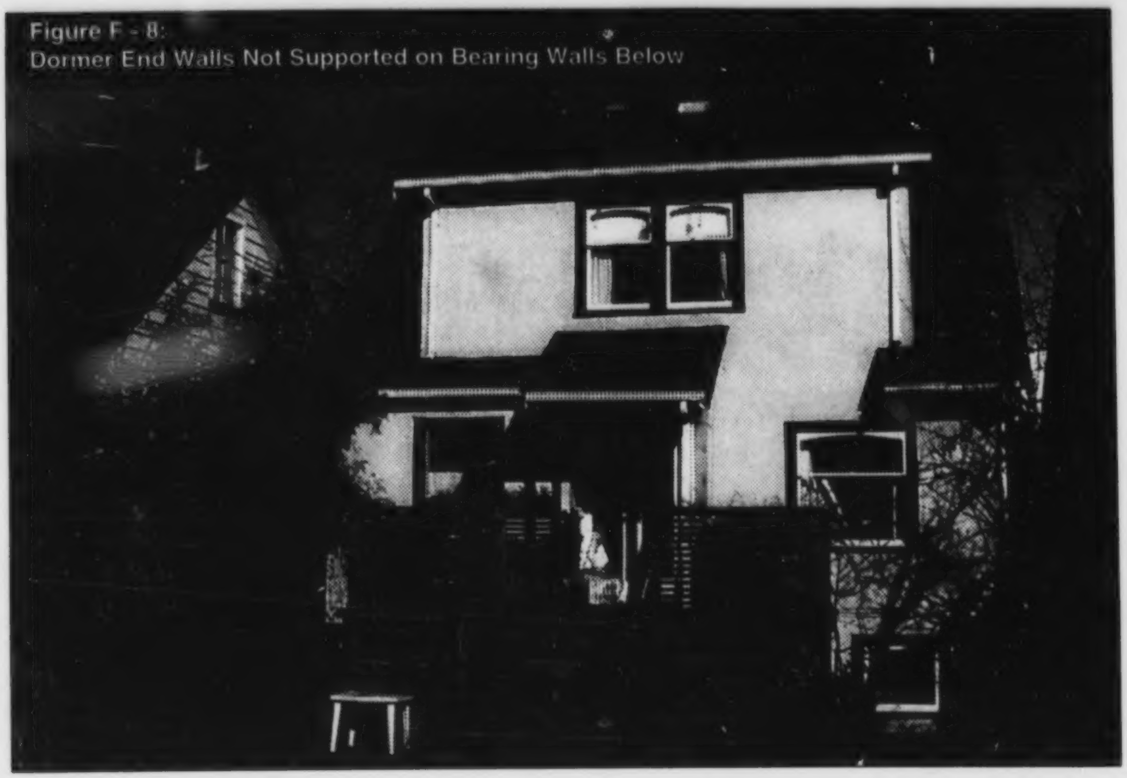
Conversely, to the east, the subject house's masonry chimney presents a collapse hazard, either onto the subject property or that of the eastern neighbour.

Figure F - 7:
Cantilevered Kitchen Condition

EXAMINING THE EXTERIOR OF THE HOUSE

A more detailed examination of the house exterior, using the checklist, reveals the following:

While the basic house is a simple box in fairly good condition, the cantilevered portion at the kitchen has a flush roof with a somewhat water stained fascia, meaning possible water ingress and associated structural weakening. Also, the cantilever breaks the flow of forces through the building to the foundations, exacerbating this weakness.



Similarly, the front and rear dormers on the house have their gable end walls bearing on floor joists below, not directly on bearing walls.

This condition may be more serious in this house than in some others, as the dormers are large, each encompassing a bedroom plus associated closet. Conversely, the dormers were built with the original house, therefore may be of better quality construction than if they were added by a "home handyman" later.

Figure F - 9:
Exterior Finishes—Stucco and Asphalt Shingles

The exterior finish materials are not bad, being stucco for walls and asphalt shingles on roofs. The stucco is original vintage, a heavy cement and stone application onto horizontal boarding behind. It may have some limited shear value, and will not be too hazardous in an earthquake.

The asphalt shingles will limit roof loads as compared to tile finishes. Fortunately, the neighbour's roofs are also asphalt shingled.

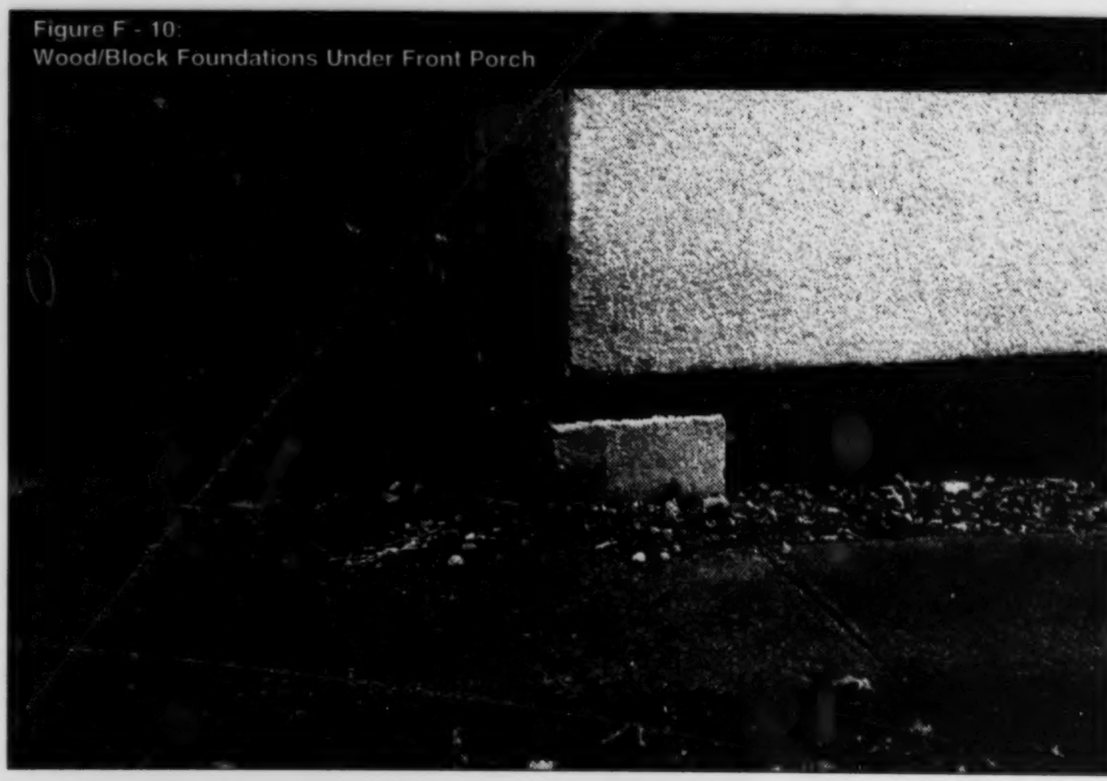


Figure F - 10:
Wood/Block Foundations Under Front Porch

All of the entries and exits from the house are problematic. The main entry porch appears solid enough, but sits on wooden construction set on concrete blocks.

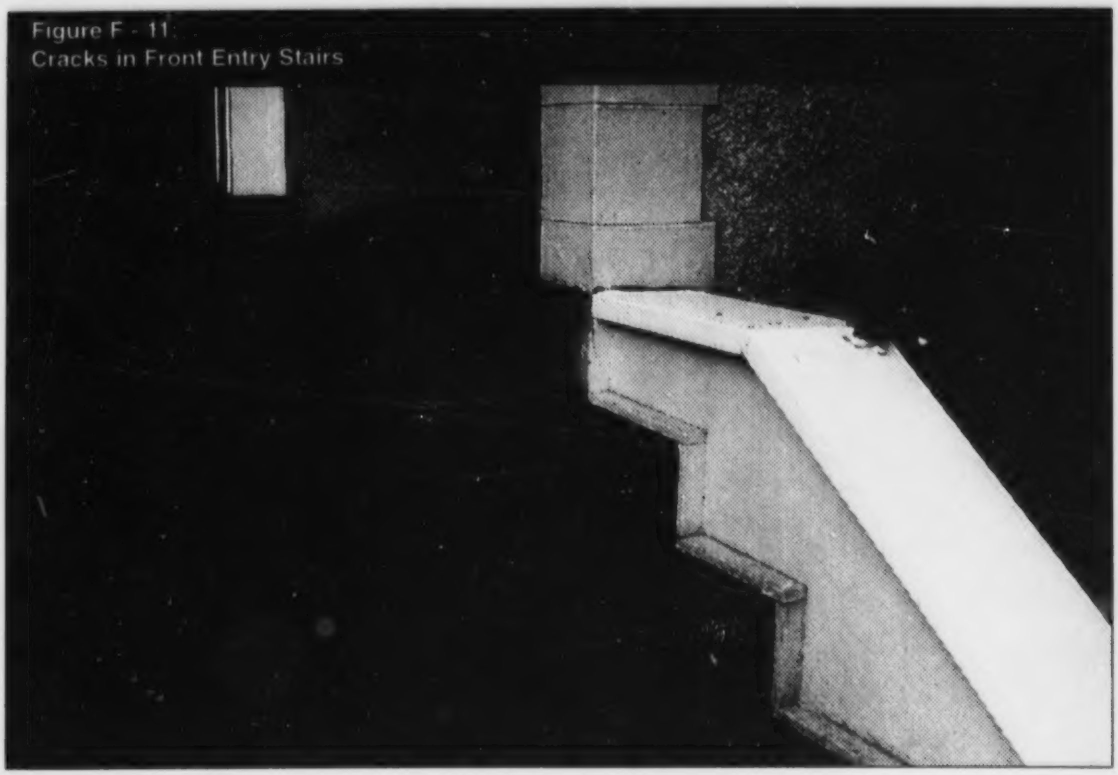


Figure F - 11:
Cracks in Front Entry Stairs

In fact, the porch has settled somewhat, cracking the stairs down to grade, which are constructed of (apparently) unreinforced concrete on wood formwork that was left in place after construction.

Figure F - 12:
Post Base Foundation Under Rear Entry Deck Area

The rear entry/egress doorway leads to a deck supported in part on original concrete piers and in part on concrete masonry piers set on subsoil. The 4" x 4" posts sit directly on the concrete and are simply toenailed onto it.

The deck itself is constructed of 2" x 4" pressure treated cedar planks on 2" x 8" pressure treated hem-fir joists, without any cross bracing between support posts.

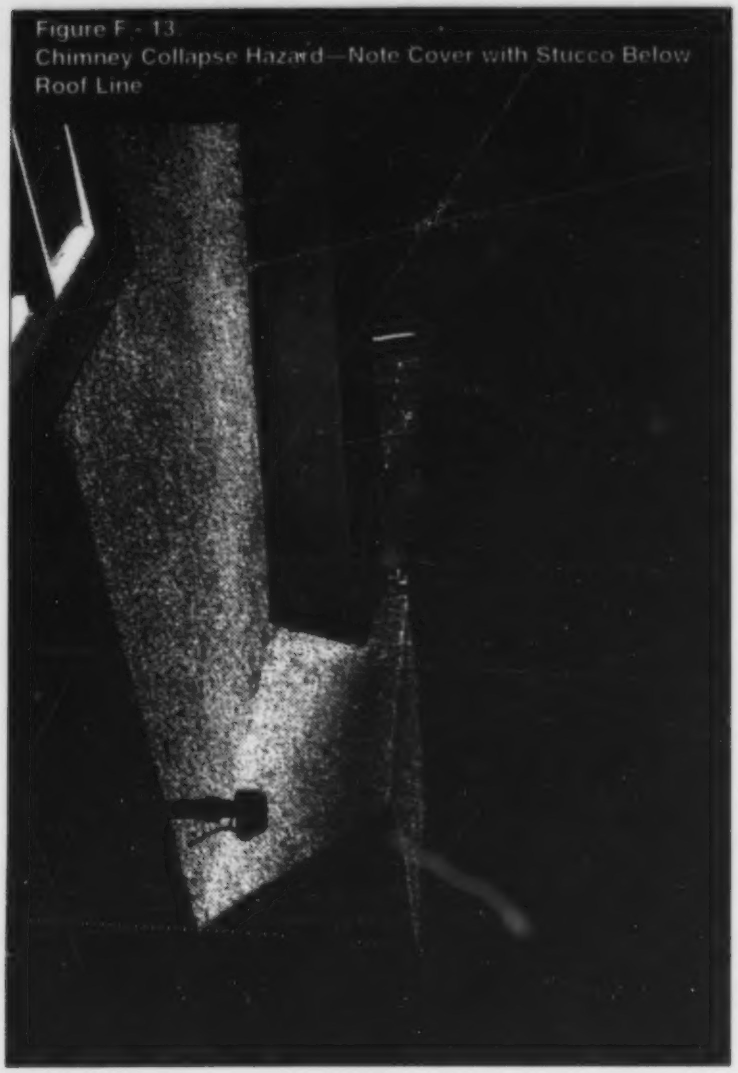


Figure F - 13
Chimney Collapse Hazard—Note Cover with Stucco Below Roof Line

Last but certainly not least, the house has two brick chimneys, one in the centre serving the hot water tank and furnace, the other at the northeast corner serving the decorative fireplace in the living room.

The central chimney is contained by wood construction except in the basement and for two to three feet above the roof peak, and will probably not be a significant collapse hazard. The perimeter chimney is a hazard. It has been strengthened below the roof line by the addition of original stucco around, but this may exacerbate the likelihood of the above roof portion collapsing.

Figure F - 14:
Cripple Wall Connection to Foundation - Note the Absence of Anchor Bolts and the Presence of a Mortar Bed Beside the Sill Plate

EXAMINING THE INTERIOR OF THE HOUSE

Foundations

By examining conditions near the back basement door of the house, it was determined that footings were present there, therefore likely around the entire perimeter. However, neither footings nor foundations in a house of this age are reinforced.

An examination of various exposed portions of the foundation found them to be in relatively good condition, without cracking, spalling or crumbling.

The foundation wall is partial height, 8" thick, with a wood cripple wall above. One wall in the centre of the basement is composed of infill studs between two 6" x 6" wood posts, which are supporting a wood beam with a partition from the floor above bearing on this. The posts are in good condition, but have no apparent connections top or bottom, that is, they are nailed at best.

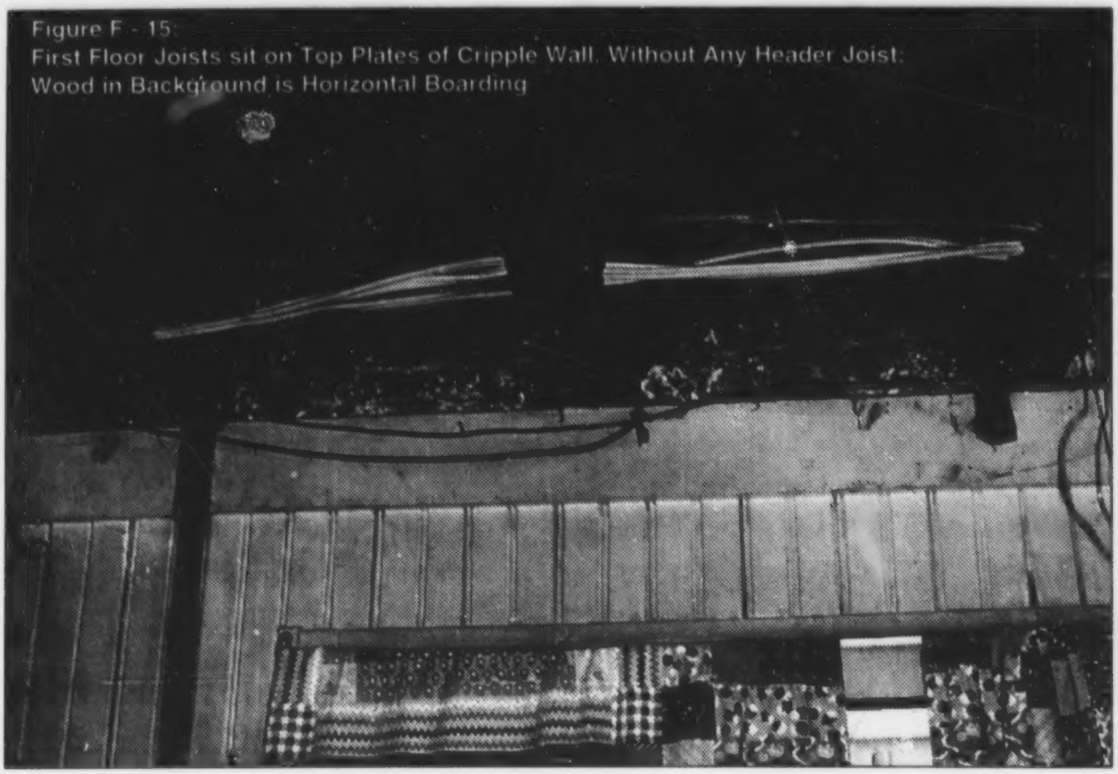


Figure F - 15:
First Floor Joists sit on Top Plates of Cripple Wall, Without Any Header Joist:
Wood in Background is Horizontal Boarding

Wood-Frame Connections to Foundations
The cripple wall studs sit on a 2" x 4" sill plate with no apparent bolting to the concrete. The sill plate does have approximately a 0.5" bed or mortar on its inside, presumably to keep the plate in place!

The framing of the building is likely balloon frame, which was common at the time of this building's construction. However, this cannot be determined until some upper floor walls are demolished.

What is apparent is that there is no continuous header or rim joist around the perimeter of the first floor. Horizontal boards are clearly visible in Figure F-15 where one would expect to see a header.

Figure F - 16:
Composite Force Paths for Case Study

Upper Floor Supporting Walls
To evaluate the conditions on the upper floors, floor plans and simple elevations of the house were drawn from measurements taken on site.

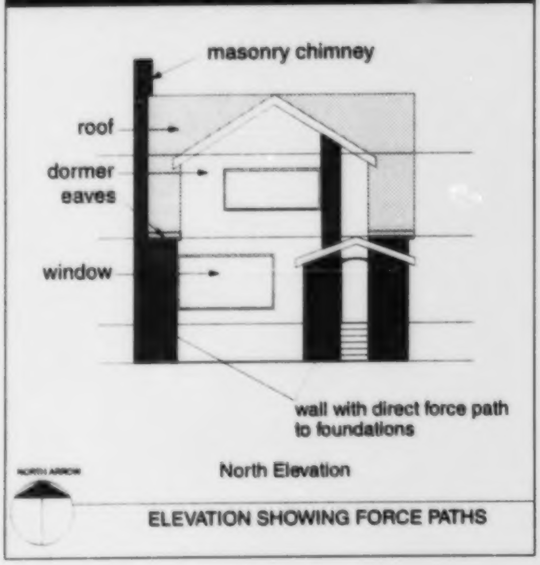
In drawing up the plans, walls carrying forces from eaves to foundations were blackened in, those not continuous were shaded in grey. Openings for windows and doors were shown as holes in the walls, as they interrupt the flow of forces. In measuring door and window openings, we allowed 50 mm (2") extra on each side of the actual opening width, as a reasonable estimate of the distance from the edge of the frame to the nearest structural framing buried in the adjacent wall. Thus a 760 mm (30") door is drawn as 860 mm (34") and a window measuring 900 mm (36") inside the frame is drawn as 1000 mm (40").

In drawing the elevations, all windows and doors were shown very diagrammatically for ease of drafting. As with the plans, portions of walls that carry loads from top to bottom of the house are shaded dark. These are the areas of prime value for adding bracing.

The plans and elevations are located at the back of this appendix.

Figure F-16 shows the composite force paths, when all of the floor plans are aligned one above the other.

Figure F-17:
North (Street) Elevation Showing Force Paths



In essence, the opportunities for bracing are limited to portions of perimeter walls together with a small increment of interior partitions.

As translated to the street (north) elevation of the house, the opportunities for bracing are shown in Figure F-17.

Contents of the House

The contents of the subject house are fairly typical, as are the problems. There are some tall pieces of furniture that may topple, some books and artwork that may fall. Both the furnace and hot water tank are unrestrained and may also topple, causing possible fire damage if a gas leak occurs, plus loss of the tank water, which is important to a post-earthquake situation.

Summary Risk Assessment

Using the summary risk assessment sheets from Appendix I provides a convenient way of bringing together the checklist content in a fashion that allows one to prepare a plan for seismic upgrading. The summaries reproduced here have been edited to delete unapplicable items.

EARTHQUAKE UPGRADE MASTER PLAN — **PROPERTY**

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
OFF-SITE HAZARDS							
From infrastructure: gas connection	Potential break		x		1	safety valve	$500.00
Utility pole at lane	Could collapse - avoid exiting this way post-quake			x			
From landscape: Neighbour's trees	Could collapse on rear egress path, maybe house - Try to convince neighbour to thin trees to reduce risk. Avoid rear as exit path.		x				
From neighbours' structures: Neighbour's chimney	Could collapse on house - Try to convince neighbour to upgrade or remove chimney			x			
ON-SITE HAZARDS:							
From accessory structures: Garage would likely collapse	No action except avoid passing by as exit path	x					
	ESTIMATED TOTAL COSTS FOR PROPERTY UPGRADE WORK	x					**$500.00**

While most of the hazards outside the house are outside of the owner's direct control, a modest investment should prevent a post-earthquake natural gas fire.

EARTHQUAKE UPGRADE MASTER PLAN — EXTERIOR

Description	Remarks	Risk 1	Risk 2	Risk 3	Units	Quantities	Estimated $
GENERAL:							
Chimneys: Masonry chimney could collapse	Remove chimney at roof line and replace with insulated metal flue, braced to roof with metal rods (not cables)			x	1	demolition ins. chimney	$500.00 $1,500.00
MATERIALS:							
Porches, sundecks and verandahs: Front and rear porches could collapse	1. Front Porch: Brace walls; excavate under and replace foundation with reinforced concrete;	x			1	excavate	$200.00
					20 ft	new foundation walls	$1,000.00
					150 ft²	Ply bracing	$150.00
					4	hold-downs	$260.00
					4	anchor bolts	100.00
	2. Rear porch: Replace footings with reinforced piers; attach posts to piers and above with metal connectors; x-brace posts below deck; use metal connectors to connect posts to roof over	x			8	10" dia. pier footings- reinforced concrete	$800.00
					8	column base connectors	$120.00
					8	column head connectors	$600.00
					8	panels x-braced	$400.00
					2	Post-to-roof metal connectors	$150.00
	ESTIMATED TOTAL COSTS FOR EXTERIOR UPGRADE WORK:						**$5,870.00**

Estimated costs for exterior work are significantly more. However, only the chimney is a high hazard item. The balance of work could be pursued in conjunction with other planned renovations, or as part of an ongoing maintenance program.

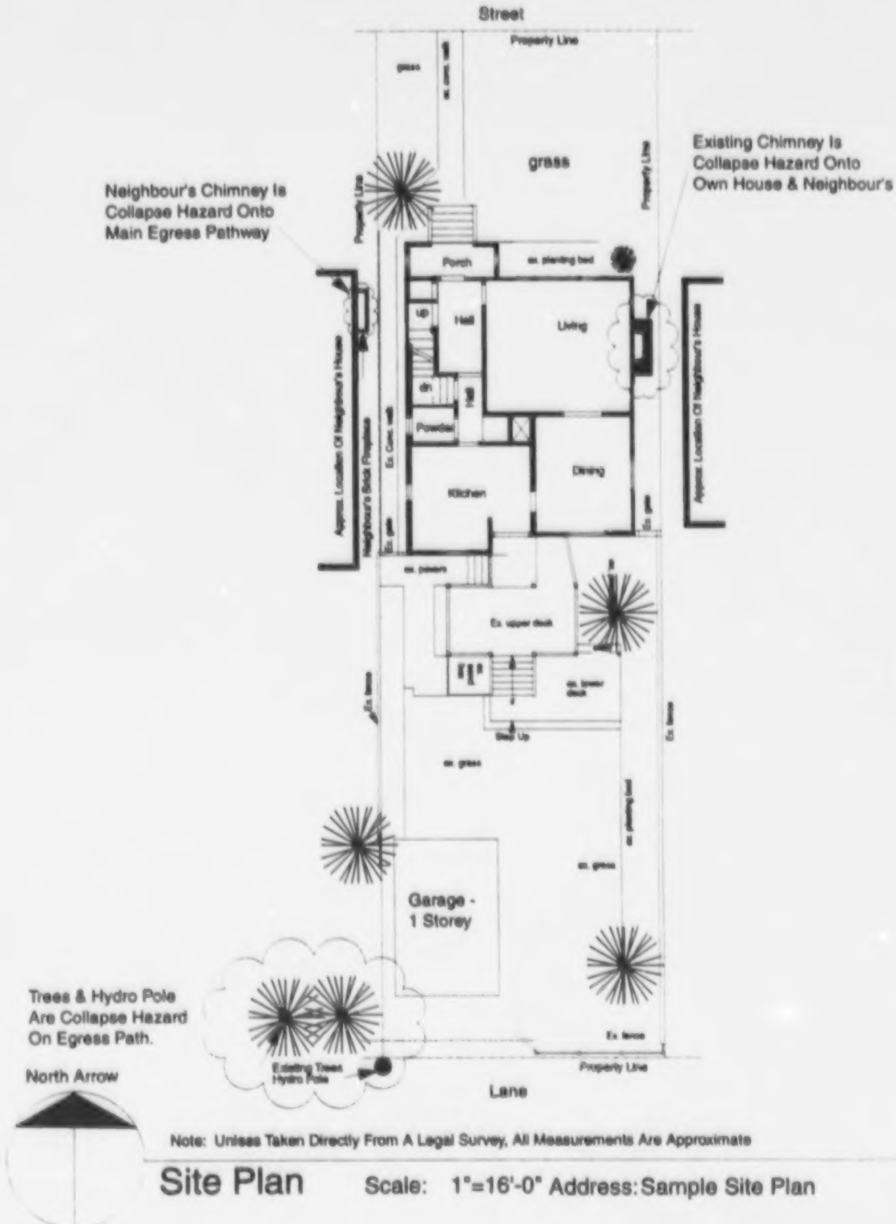
EARTHQUAKE UPGRADE MASTER PLAN — INTERIOR

Description	Remarks	Risk 1	Risk 2	Risk 3	Units	Quantities	Estimated $
INTERIOR:							
Foundations: Concrete is unreinforced	Add extra anchor bolts to distribute loads better		x			see below	
Interior posts in basement are nailed only, not braced in any way	Use metal connectors to attach at top and bottom. Infill around posts to create true plywood shear wall. Connect basement roof beam to adjacent joists with metal connectors		x		2 2 24 ft 4 20	post bases post caps studs & plywood bracing anchor bolts joist-to-beam metal connectors	$300.00 $150.00 $350.00 $50.00 $100.00
Cripple Walls: Cripple walls are not braced	Brace all cripple walls		x		1 120 ft 50 ft	demolition access to cripple walls cripple wall bracing - 1/2" plywood well nailed refinish walls c/w drywall, insulation, vapour barrier and paint	$200.00 $450.00 $1,000.00
Corners: no anchor bolts or hold-downs	Add anchor bolts around perimeter @ 4' o.c., 2 hold-downs each corner		x		28 4	anchor bolts x2 hold-downs/corner	$500.00 $520.00
Structural Connections: Old frame has no discernible connections between floors except nails	Add hold-downs each corner of each floor-to-floor connection; expose 25% of frame from inside or out and brace		x		30 ft x 2 floors 500 ft² 12 8	remove ex. stucco braced wall - ply. v/b. insulation corners - hold-downs - includes roof corners retrim and refinish	$500.00 $2,000.00 $1,560.00 $1,600.00
	ESTIMATED TOTAL COSTS FOR INTERIOR UPGRADE WORK:						**$9,010.00**

The interior of a house will usually register the most expensive upgrade requirements. In this case, an investment of $3,350.00 (less if the owner does some of the work) will secure the building to its foundations, the lack of which is responsible for up to 3/4 of the property damage in a major earthquake. The remainder of the work noted above is required to better connect and brace the roof and floors.

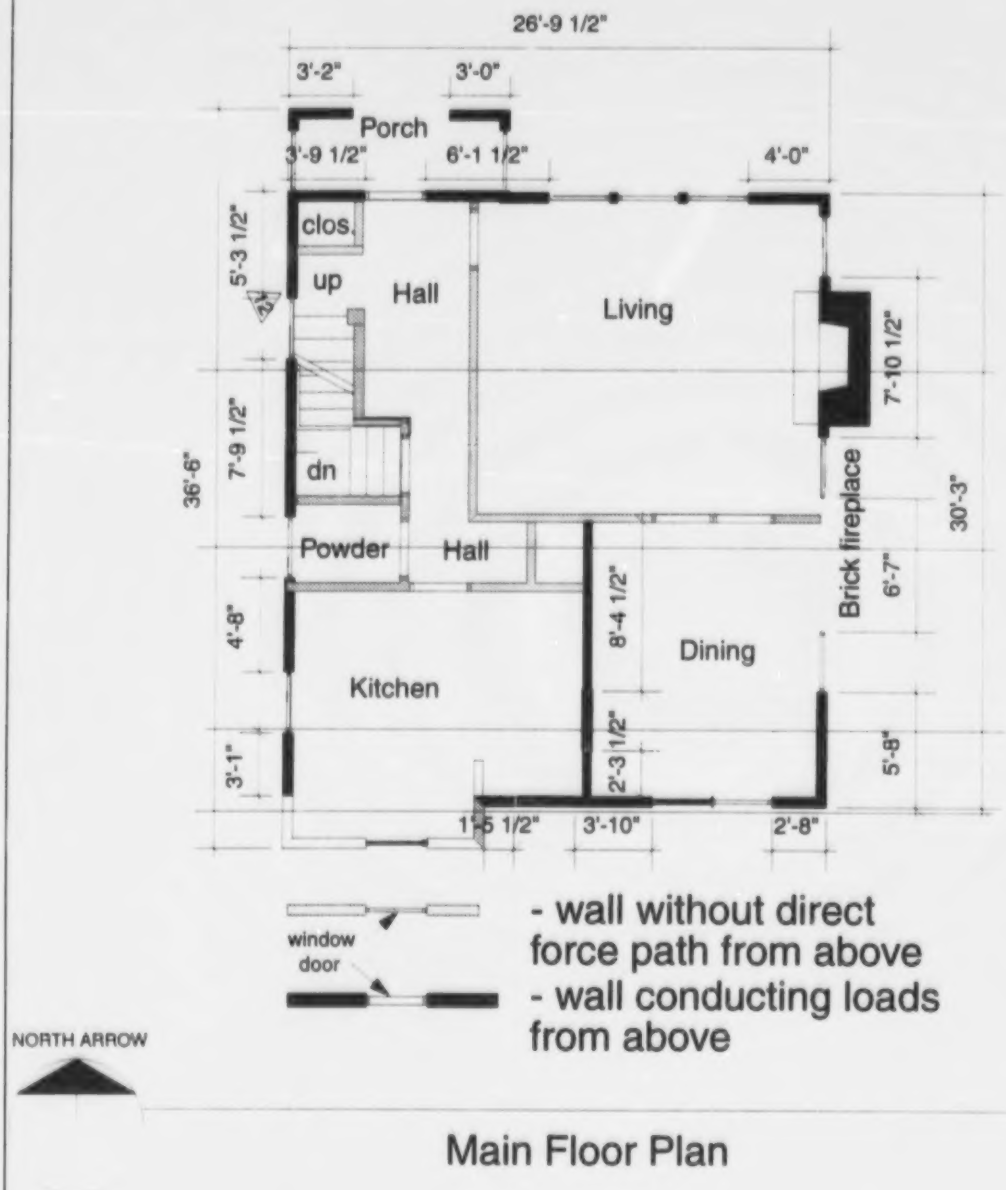
Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
CONTENTS:							
Furniture: Tall furniture may fall	Fix furniture to walls with brackets	x			12	pieces @ 2 brackets each - owner install	$60.00
Books: Books may fall off shelves	Investigate shelf restraints. Put heavy books at bottom of shelves	x					
Dishes and glassware: Will fall and break	Add latches to cabinets and drawers; stick down loose display items using purpose made adhesive	x			20 1	cupboard latches - owner install adhesive	$50.00 $10.00
Displayed items: Artwork will fall off walls	Move away from beds, etc., for lighter items, clamp hooks to fix better; for heavier items, use heavy duty connectors to studs.	x			15	heavy duty connectors - owner install	$60.00
Electrical fixtures: Basement fixtures may fall	Connect safety cables from fixtures to structure to prevent fall	x			4	cables - owner install	$10.00
Water Tank: would collapse	Strap down	x			1	each strap down by contractor	$75.00
Furnace: would collapse	Strap down. Replace gas connections with flexible connections	x			1 1	each strap down by contractor flexible gas connections	$75.00 $150.00
	ESTIMATED TOTAL COSTS FOR CONTENTS UPGRADE WORK:						**$ 490.00**

In this case study, an investment of less than $500.00, plus the owner's labour, will secure as much of the house's contents as reasonably possible from earthquake damage.

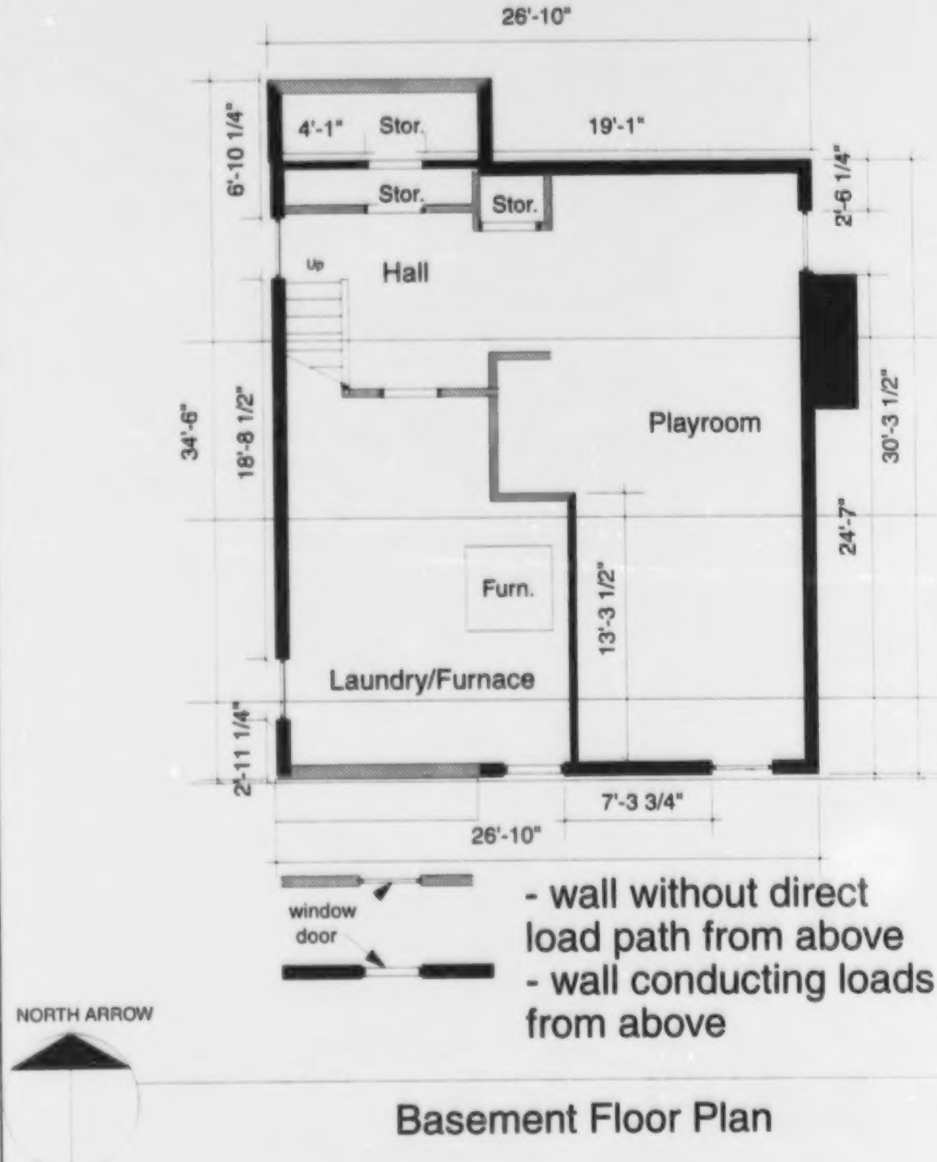


Note: Unless Taken Directly From A Legal Survey, All Measurements Are Approximate

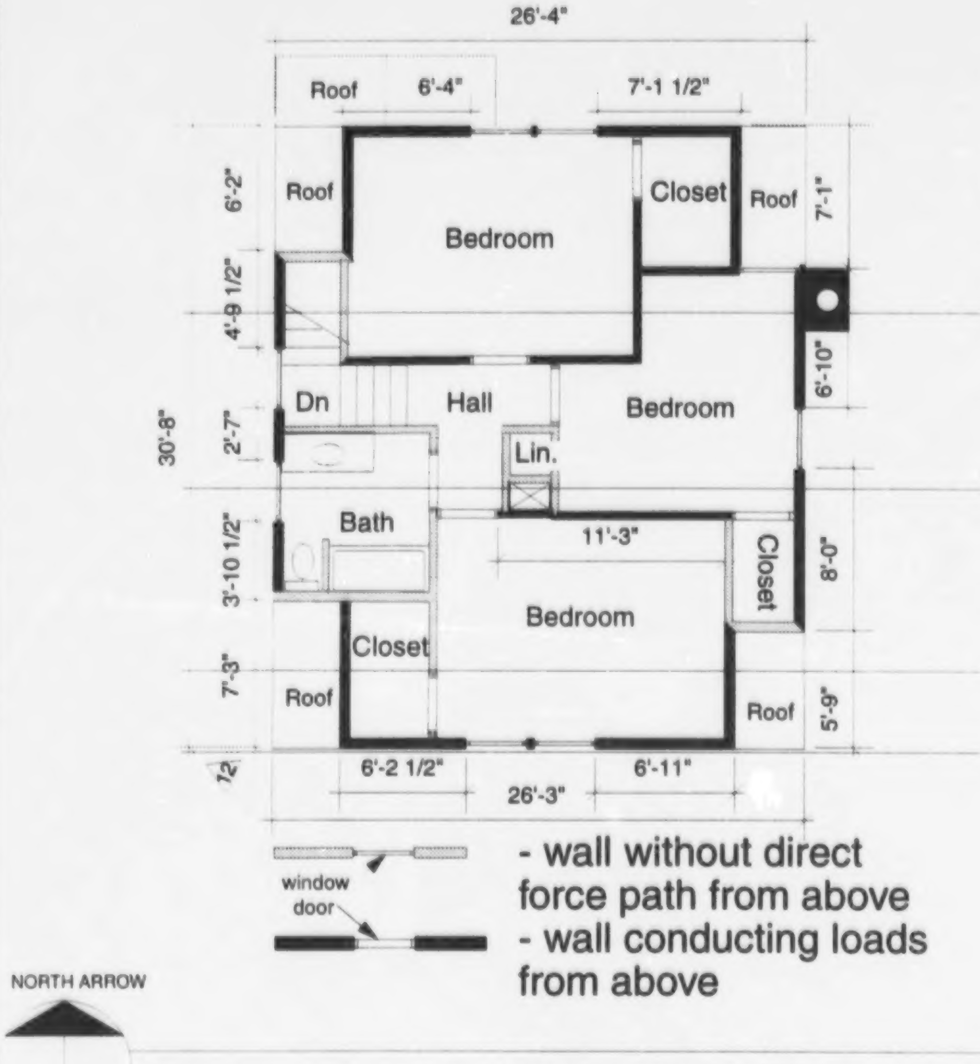
Site Plan Scale: 1"=16'-0" Address: Sample Site Plan



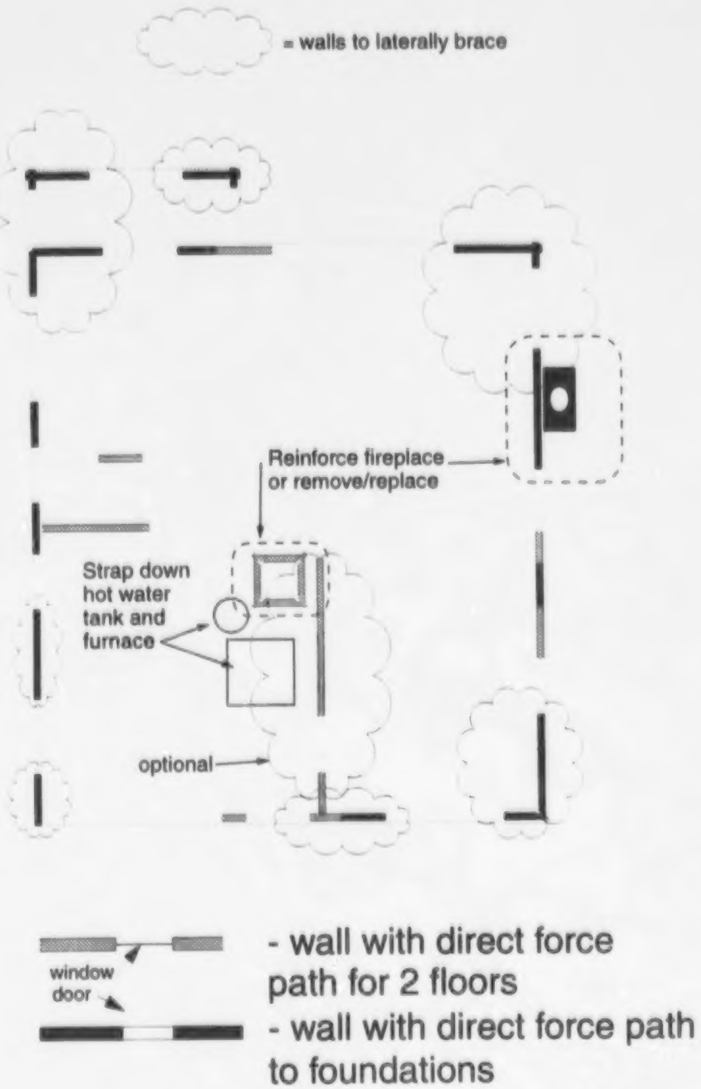
Main Floor Plan



Basement Floor Plan

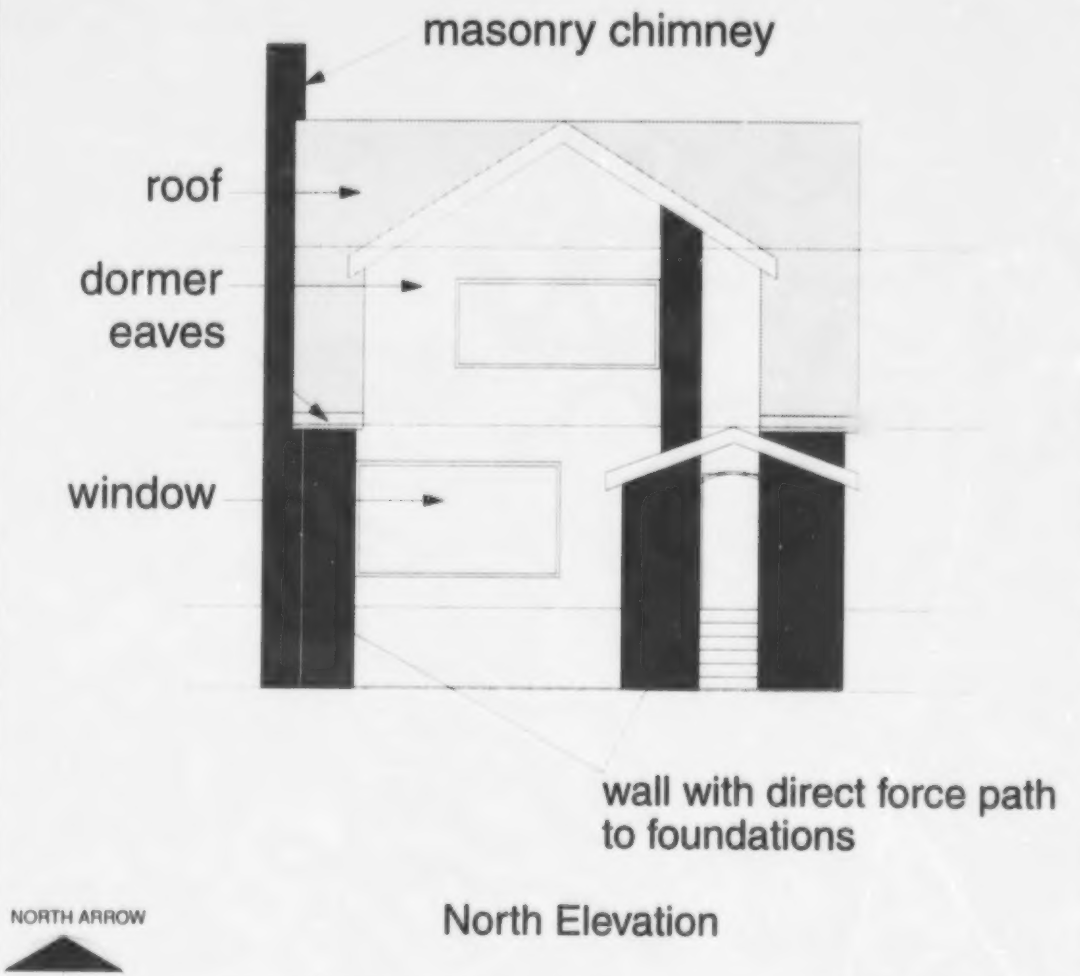


2nd Floor Plan



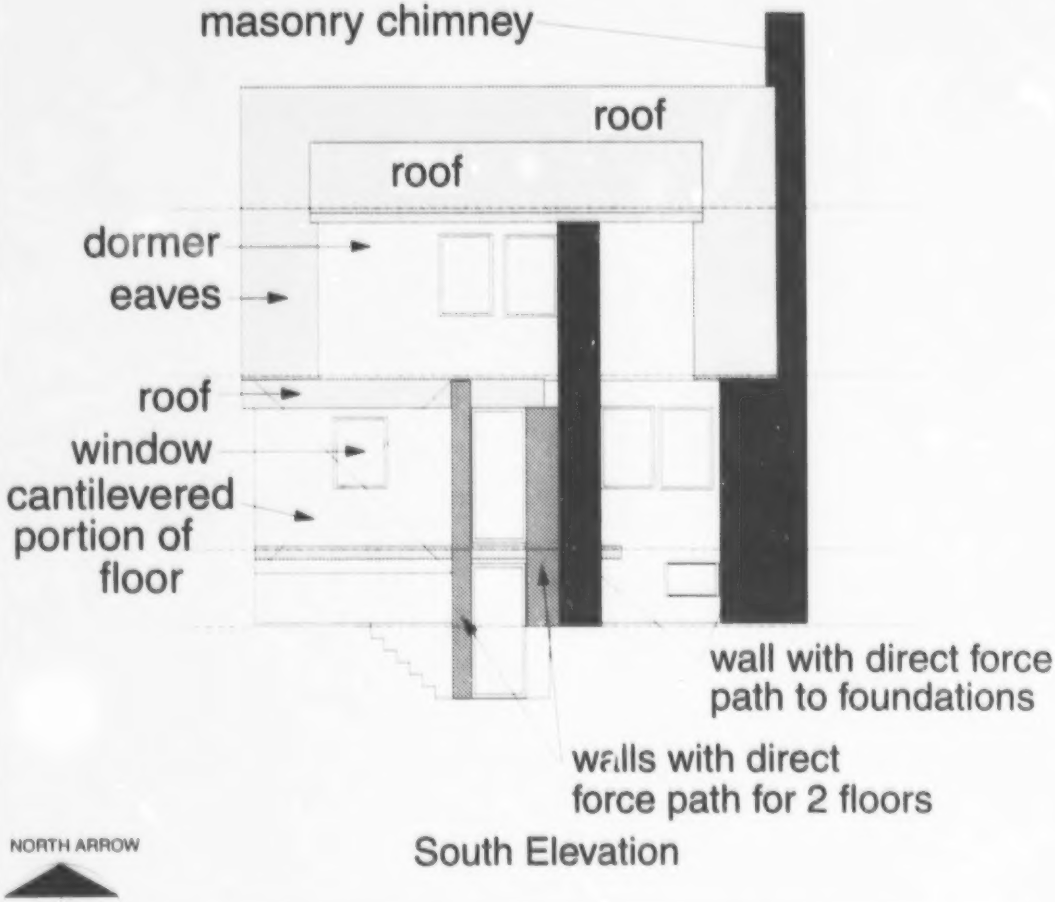
Plan of Composite Force Paths
& Summary or Recommended Upgrading

FLOOR PLAN

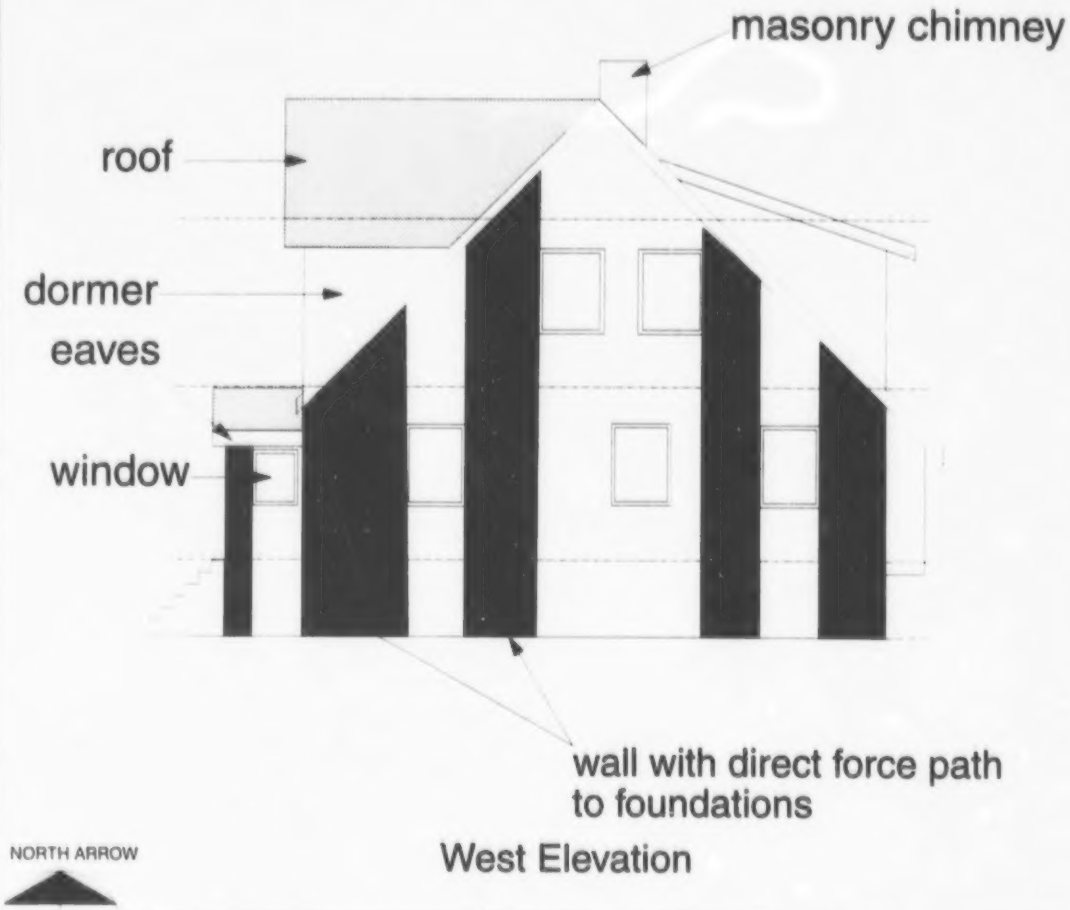


North Elevation

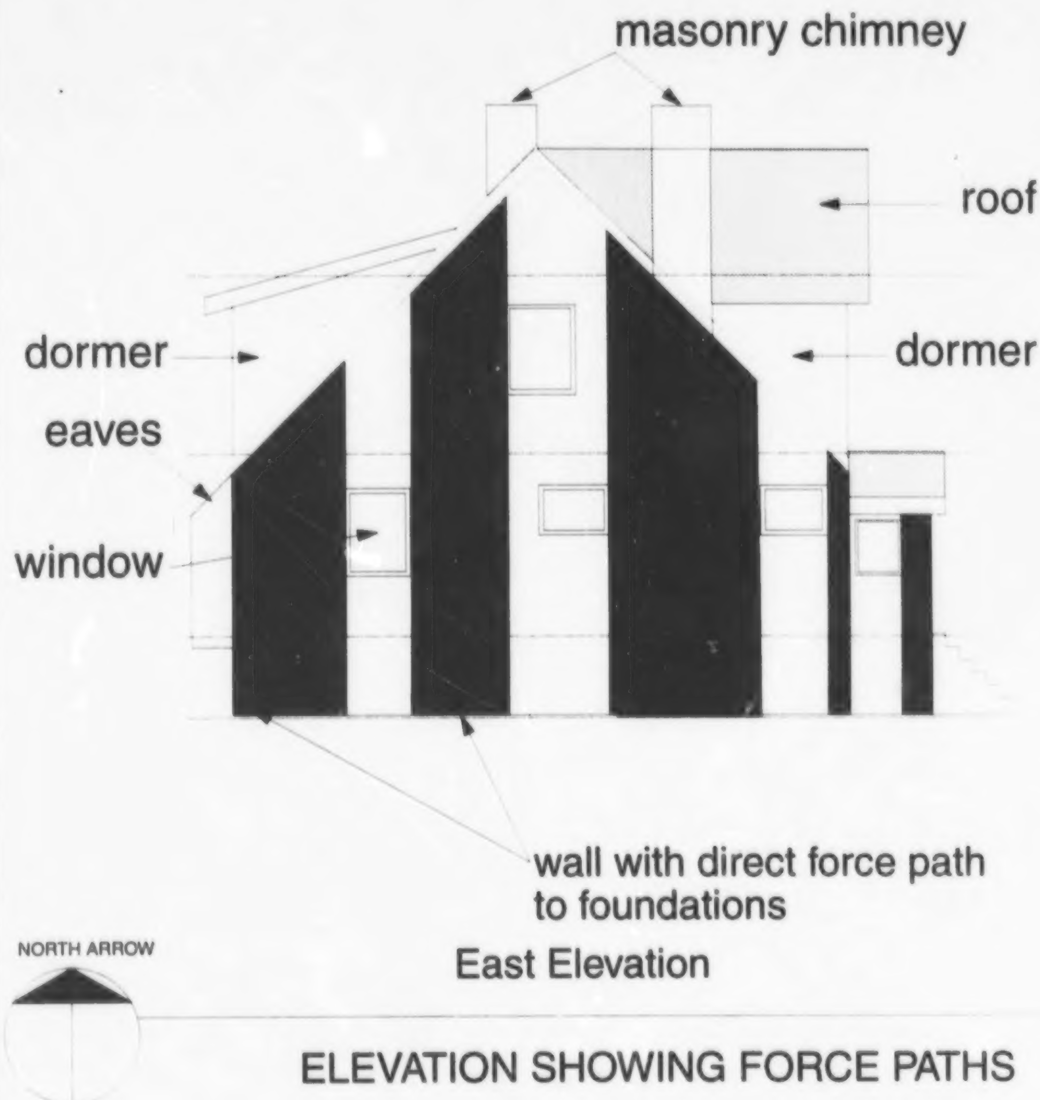
ELEVATION SHOWING FORCE PATHS



ELEVATION SHOWING FORCE PATHS



ELEVATION SHOWING FORCE PATHS



East Elevation

ELEVATION SHOWING FORCE PATHS

APPENDIX G

GLOSSARY OF TECHNICAL TERMS

APPENDIX G
GLOSSARY OF TECHNICAL TERMS

Aftershock	Small earthquake or tremor that follows a major earthquake.
Anchor bolt	A steel rod used to tie a wood sill plate to a foundation.
Bearing wall	A wall providing support for vertical loads (a structural wall).
Bottom plate	Performs similar function to a sill plate, except connects a stud wall frame to the floor construction on which the wall sits.
Braced frame or braced wall	Acts in the same manner as a shear wall, though it normally provides lower resistance to earthquake forces.
Cladding	Describes the exterior material(s) of a house that are visible to the eye, for example brick, wood or metal siding, stucco and shingles.
Configuration	Used in the context of seismic conditions, is defined as building size and shape, but includes the nature, size and location of both structural and nonstructural elements that affect the structural performance.
Cripple wall	Also called a crawl space wall or pony wall, this is the short wood wall that supports the floor system above the foundation. In some cases it elevates the house above the ground and provides a "crawl space." In other cases, the cripple wall is an extension of the foundation wall, forming a basement for the house. On sloping sites it may be quite high, if located on the downhill side of the house.
Delta	A nearly flat plain of alluvial, often triangular deposit between diverging branches of the mouth of a river.
Diaphragm	Horizontal system designed to transmit seismic forces to the vertical elements of the lateral force-resisting system.
Egress route	A means of exiting from a structure or area, generally after an earthquake is over. Not to be confused with an exit route, which is a means of escaping a building, usually prescribed by building codes. In some instances exit routes may be inappropriate as egress routes.
Fascia	Strip of wood or vinyl that finishes the roof edge; decorative, not structural.
Fault	A break in the continuity of a body of rock or of a vein, with dislocation along the plane of the fracture (fault plane).
Finish materials	Materials visible to the eye, both interior and exterior, forming the exposed finish in construction, for example carpet, paint and wood trim.
Force path (load path)	The vertical path or paths through which earthquake forces are conducted continuously through a building frame to the ground.
Header	Wood framing member placed at right angles to horizontal framing members such as joists.

Joist	Horizontal supporting members, smaller than beams.
Lateral bracing	Bracing that prevents vertical members or walls from tilting, that is, distorting horizontally. This bracing is usually diagonal.
Ledger	A supporting wood member that is bolted to a foundation or wood wall.
Moment-resistant frame	Frame made of orthogonal elements (no diagonals) which, by very stiff connections, resists distortion.
Mud sill	Another term for sill plate.
Oriented Strand Board (OSB)	Structural panels made from wood wafers bonded with a waterproof adhesive.
Parapet	Continuation of a wall above the roof plane.
Pony wall	See "cripple wall."
Racking	A twisting movement that can distort or destroy a framework.
Rafter	Inclined framing member supporting a pitched roof.
Retrofit	Adding bracing, anchoring or other improvements to the structure, after the original construction is completed - the word "upgrade" is used in this *Guide*.
Rim joist	See "header."
Seiches	A random oscillation of the water of a lake, bay, etc. caused by wind or earthquake.
Seismic	(also seismal, seismical). Pertaining to, of the nature of, or caused by an earthquake or vibration of the earth, whether due to natural or artificial causes.
Shear wall	Wall designed to receive lateral forces from floor and roof diaphrams and transmit them through the foundation to the ground, and having the ability to resist forces that are reversing their direction, which is characteristic of an earthquake.
Sheathing	A sheet material such as plywood that spans between small framing members such as studs and joists, helping to tie them together and form a base for attachment of finishes.
Sill plate	The framing member that sits atop a concrete or masonry foundation wall and may be bolted to it. Also known as a mud sill, although this latter appears to be mainly an American term.
Stand-off post base	A steel connector between the bottom of a wood post and the concrete pier or footing to which it is connected. Refer to *Guide* Detail Q3 for a typical base.
Steel column base	Used to connect wooden column to bases supporting a concrete or wood structure.
Steel framing and angle connector	Multi-purpose device used for assuring connections between studs to plate joists to beam and rim joist to plates.
Steel hold-down	Used to transfer tension loads between elements such as walls to floors or foundations.

Steel joist hanger	Used for connecting one horizontal wood member to another such as a joist to a beam.
Steel post cap and column cap	Used to connect wooden post to beam.
Steel tension tie	Often applied to the outside face of the framing to tie an upper wall to the wall below.
Steel truss connector	Available to connect a variety of configurations, to walls, beams, or one another.
Stud	Vertical framing member of small cross section, usually 38 x 89 mm (2" x 4") or 38 x 140 mm (2" x 6"). Usually spaced at 400 mm (16") on centre spacing or less, studs are the vertical structural elements in a wall.
Subduction	The process by which collision of the earth's crustal plates results in one plate's being drawn down or overriden by another, localized along the juncture (subduction zone) of two plates.
Tectonic	Pertaining to the structure of the earth's crust; also referring to the forces or conditions within the earth that cause movements of the crust; designating the results of such movements: tectonic valleys.
Top plate	Corresponding to the sill plate; horizontal studs that join the vertical wall studs and also connect separate walls together at their intersection; becomes the seat of floor joists above.
Tsunami	An unusually large sea wave produced by a seaquake or undersea volcanic eruption.
Upgrade	Adding bracing, anchoring or other improvements to the structure, after the original construction is completed. The word "retrofit" is also used.

APPENDIX H

CHECKLISTS

APPENDIX H
CHECKLISTS

The documents that follow include masters of the four checklists developed for use with this *Guide*.

	EARTHQUAKE EVALUATION	CHECKLIST A EVALUATING THE PROPERTY
Item #	**Conditions to Check**	**Notes** **Property Address:** ____________________
A1	**GEOLOGY OF THE SITE AND THE AREA**	
A1.1	❑ **Known Faults:** • Is the house located on or near a recorded fault? ❑ **No** ❑ **Yes**	• Fault records in Canada are not well developed. • Most earthquakes in Canada do not show as breaks on the surface.
A1.2	❑ **Hills, Cliffs and Ridges:** • Is the house sited on the brow, the slope or at the foot of a hill? ____________________ • Is the house sited atop or at the base of a cliff? ____________________ • Is the house located on a ridge? ❑ **No** ❑ **Yes**	• Slopes are generally less stable than flat surfaces. • Slopes may collapse under the house. • Slopes may collapse onto the house from above. • Houses on cliffs experience relatively more earthquake movement than those on level ground. • Houses on ridges experience relatively more earthquake movement than those on level ground.
A1.3	❑ **Wet Areas:** • Is the house located near a surface or subsurface watercourse? ❑ **No** ❑ **Yes**	• Houses located on present and former wet areas experience relatively more earthquake movement than those located on other soil conditions.
A1.4	❑ **Soils:** • What type of soils underlie the house? ❑ rock ❑ stiff soil over rock ❑ deep soil (up to 12 m) with clay-like soil in the first 6 m ❑ soil with more than 12 m of soft, clay-like material	• Those at the top of the list are generally better from a seismic standpoint.

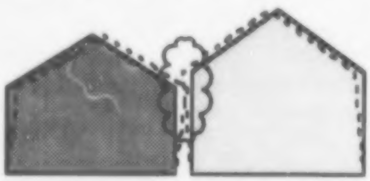
Risk	Recommendations	GUIDE References
1 2 3	For each checklist item that applies to the house, assess the relative risk of the existing condition and assign a risk factor: 1 = Possible Loss of Property; 2 = Possible Loss of Shelter; 3 = Possible Loss of Life.	
	• Chapter 3 of the *Guide* provides a general discussion of geological conditions affecting building sites. • Houses near the specific geological conditions noted should be designed to withstand the highest expected earthquake forces. • Check municipal engineering and building departments for further information regarding the geological conditions of your area. • Seek expert advice when considering property with the following known or suspected types of conditions.	p. 40
	• Contact Natural Resources Canada for further information regarding faults in your area. • If you are near a fault, upgrade to the maximum extent recommended in the *Guide*.	p. 40
	• Look for evidence in the neighbourhood of subsidence or collapse. • On property where the slope has been cut or filled, confirm the integrity of soil, retaining walls, and drainage systems. • Upgrade to the maximum extent recommended in the *Guide*. • Upgrade to the maximum extent recommended in the *Guide*.	p. 40
	• Seek expert advice on upgrading when faced with these kinds of conditions. • Check municipal engineering and building departments for further information regarding the geological conditions of your area.	p. 40
	• Check municipal engineering and building departments for further information regarding the geological conditions of your area. • Where Class 3) and 4) soils, are encountered, use expert advice for design to resist seismic reactions imposed by these soil conditions.	p. 42

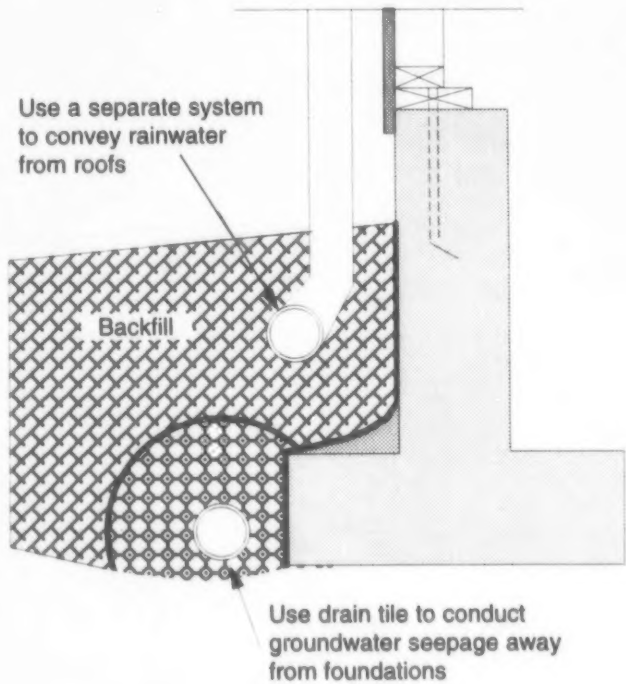
EARTHQUAKE EVALUATION		CHECKLIST A EVALUATING THE PROPERTY
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________________
A2	**SITE FEATURES**	
A2.1	❑ **Tall Trees:** • Could tall trees hit the house (or accessory structures) in the event of their falling? ❑ **No** ❑ **Yes**	• Shallow rooted species are more prone to toppling. Some trees do well in groves, but are weak as individual specimens.
A2.2	❑ **Swimming Pools:** • Is there a pool on the site? ❑ **No** ❑ **Yes**	• Water escaping from pools can cause excessive property damage. • There is little which can be done to protect pools from local ground disturbances.
A2.3	❑ **Utility Poles:** • Is the house close to utility poles? ❑ **No** ❑ **Yes**	• These often collapse during an earthquake, obstructing exit paths and possibly endangering life.
A2.4	❑ **Accessory Buildings:** • Does the house have accessory structures such as free standing garages, workshops, garden sheds? ❑ **No** ❑ **Yes**	• These are often less well built and maintained than the house and thus more subject to collapse.
A2.5	❑ **Retaining Walls and Free Standing Walls:** • Are there any retaining walls around the property? ❑ **No** ❑ **Yes** • Are they above or below adjacent neighbours' ground levels? ______________________ How high are they? ______________	• Because retaining walls are unevenly loaded, and often not designed for hydrostatic pressures or seismic loads, they present a collapse hazard.
A2.6	❑ **Underground Utilities:** • **Gas:** Where are the connections to gas, propane or similar services? ______________________ • **Water:** Where does the house connect to water and sewers? ______________________	• These are subject to rupture in an earthquake, which may cause a fire. • These are subject to rupture in an earthquake. While such ruptures are not life threatening, they will need repair and could cause things like effluent backup into the home.

Risk	Recommendations	GUIDE References
	• If the large trees are retained, have their condition assessed by an arborist. The potential hazard can be reduced by care and maintenance. • Have the root system of trees close to the house checked.	p. 44
	• Maintain the pool structure, and any retaining walls associated with the pool. • New pools should be positioned on solid soils or be thoroughly designed to resist seismic movements.	p. 44
		p. 44
		p. 44
	• Protect top of walls from exposure from rain and snow with a weather cap. • Retaining walls should be further protected from saturated soils using a membrane-type waterproofing. • Reinforce walls with significant loads, especially on slopes. • Provide foundation drainage system.	p. 44
	Gas: • Know the location of the shut-off valve and store a wrench of the correct size nearby. • Consider installing an automatic seismic shut-off valve. **Water:** • Maintain an emergency supply of drinking water. • Know the location of your water shut-off valves. Store the tools needed to close the valves in a convenient location near the valves. • Consider installing an automatic valve that will shut off water to the house in the event of an earthquake. **Fire protection:** • In addition to a fire extinguisher in the house, install a unit in vehicles and accessory buildings on the site.	p. 46

EARTHQUAKE EVALUATION

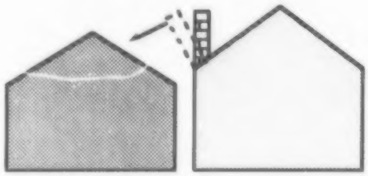
CHECKLIST A
EVALUATING THE PROPERTY

Item #	Conditions to Check	Notes **Property Address:** ______________________
A2.7	❑ **Foundation Drainage:** • Does the house have foundation drains? **❑ No ❑ Yes ❑ Can't tell**	• The absence of foundation drains may leave soils saturated, making foundations and retaining walls more prone to failure during earthquakes.
A2.8	❑ **Neighbours' Hazards** • How close is the house to its neighbours? Side yard #1 = _____; Side yard #2 = ______	As buildings sway in an earthquake, they may pound each other if they are too close. 

Risk	Recommendations	GUIDE References
	• Clean out and repair existing drainage in association with any renovations. • Provide foundation drainage in association with any work involving foundations or retaining walls. • Foundation and roof drainage systems should be independent of one another. Use a separate drainage system or a soak-away rock pit for roof drainage.  	p. 48
	• Avoid planning emergency exits from a house that pass through side yards. • Evaluate the features of neighbours' properties and houses for possible impact on your safety.	p. 50

EARTHQUAKE EVALUATION

CHECKLIST A EVALUATING THE PROPERTY

Item #	Conditions to Check	Notes
		Property Address: ____________________
	• Do the neighbours' houses have chimneys or other elements facing your property which might fall? ❑ **No** ❑ **Yes** **Describe:** ____________________  • Is a neighbour's house substantially taller than your house? ❑ **No** ❑ **Yes**	• These elements are very subject to collapse and may damage your house and in extreme situations, knock it off its foundations. • Experience shows that falling masonry is a major hazard during earthquakes.
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	

Risk	Recommendations	GUIDE References
	• Avoid planning emergency exits from a house which pass through side yards. • Evaluate the features of neighbours' properties and houses for possible impact on your safety.	p. 50

EARTHQUAKE EVALUATION

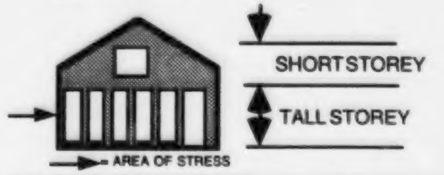
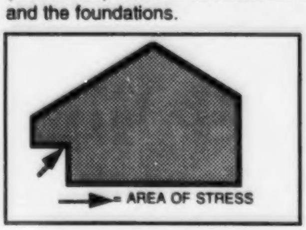
CHECKLIST B EVALUATING THE EXTERIOR

Item #	Conditions to Check	Notes **Property Address:** ______________________
B1	**CONDITIONS AND CONSTRUCTION OF THE EXTERIOR**	
B1.1	❑ **General Condition of Exterior:** • Describe the general state of repair of the house.	• The general condition of a house is a good indicator of its seismic worthiness.
B1.2	❑ **Grade Conditions:** • Where the house meets the ground, is there (or has there been) any wood in direct (or close) contact with the earth? ❑ **No** ❑ **Yes** Does groundwater flow against the side(s) of the house? ❑ **No** ❑ **Yes**	• The connection of the wood frame of the house to the foundation and earth is a zone of high seismic force and frequent house failures.
B1.3	❑ **Construction of the Exterior:** • What is the approximate age of the house? ______________________	• Depending on when the house was constructed, the placement and size of doors and windows, the type of wood structural frame, and particularly the type of sheathing, will vary. All are factors in the seismic characteristics of the house.

B2	**CONVENTIONAL HOUSE TYPES**	
B2.1	❑ **House Type:** • What is the basic house configuration and number of storeys? ❑ **Bungalow** ❑ **Cripple Wall House: Storeys=** ________ ❑ **Taller House: Storeys =** ________ ❑ **Split Level:** **Maximum Storeys =** ________	• See descriptions and illustrations of house types in Section B, Evaluating the Exterior. • Two categories may apply to a house.

Risk	Recommendations	GUIDE References
1 2 3	For each checklist item that applies to the house, assess the relative risk of the existing condition and assign a risk factor: 1 = Possible Loss of Property; 2 = Possible Loss of Shelter; 3 = Possible Loss of Life.	
	• Look for areas where water might be entering the exterior material of the house.	p. 54
	• Where wood has been in proximity of the ground, check for decay or insect damage and repair if materials are degraded. • Provide a minimum of 200 mm (8") separation between wood and earth. • Contour the land to encourage water run-off to move away from the foundation. • Locate the discharge of downspouts so they do not dump water near the foundation. • Run site and roof drainage in a piped system which is independent from the foundation/ footing drainage system for the house.	p. 54
	Use the checklist categories which follow to: • Assess the significance of the house geometry, • Determine the extent and type of sheathing materials, • Determine how materials are connected, • Determine the extent and type of exterior finishes, • Verify presence and condition of foundations, • Determine if the house is supported on cripple walls.	p. 54

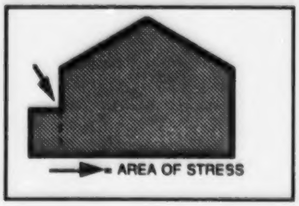
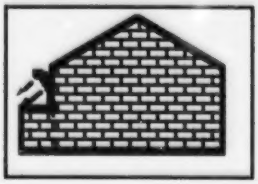
	• If a vertical extension is contemplated, expect to reinforce the existing wood structures and foundations below to compensate for the additional seismic loads it imposes. To successfully resist seismic forces, design must exceed the basic requirements of the building code in force.	p. 56

	EARTHQUAKE EVALUATION	CHECKLIST B EVALUATING THE EXTERIOR
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________________
B3	**GEOMETRY OF THE HOUSE**	
B3.1	❑ **Shape:** • Is the basic shape of the house a simple rectangle (or square)? ❑ **No** ❑ **Yes** (make a simple sketch the shape of the house on this page)	
B3.2	❑ **Unusual Storey Height:** • Is one of the storeys of greater height relative to the others (for example, more than 20% greater)? ❑ **No** ❑ **Yes**	• An unusually high floor to ceiling height may create a "soft storey" effect. 
B3.3	❑ **Overhanging Storeys (Cantilevers):** • Are there any conditions where upper storeys overhang the walls below? ❑ **No** ❑ **Yes** What is the construction of the overhanging structure? ______________________ ______________________ What is the construction of the supporting structure below? ______________________ ______________________	• Increased loads caused by overhanging storeys (cantilevers) increase stresses on the storeys below and the foundations. 

Risk	Recommendations	GUIDE References
	• If an addition is contemplated, try to use the opportunity to improve the symmetry of the house. • If the addition creates an asymmetrical condition, design the connections between the addition and the existing house to resolve the concentrated stresses. • Or, re-evaluate plans to determine if a design plan with better seismic characteristics can be found.	p. 62
	• Upgrade the connections between the high storey and those above and below, as well as increasing the stiffness of the high storey.	p. 62
	• Consider the construction of columns below the projecting floors, structurally connected to the floors of the overhanging storeys, to new foundations below, and braced to the main structure. • Where columns are not feasible or desirable, diagonally brace the overhanging element back to the main frame. In this instance, the main frame will need strengthening to withstand the added loads.	p. 64

EARTHQUAKE EVALUATION

CHECKLIST B
EVALUATING THE EXTERIOR

Item #	Conditions to Check	Notes
		Property Address: ______________________
B3.4	❑ **Setback Storeys:** • Are upper floors of the house set back from floors below? ❑ No ❑ Yes • Where floors are set back, are the resulting shed roofs or decks well drained and flashed? ❑ No ❑ Yes What is the construction of the roof or deck adjacent setback walls? ______________________ ______________________ • Is the exterior finish material of walls of the setback area masonry? ❑ No ❑ Yes	• Setback storeys whose structural walls do not carry directly through to the walls below, are more subject to damage in an earthquake.  • Contrary to building codes, masonry walls, located on setback stories, are often supported on wood structural members rather than steel members. 
B3.5	❑ **Roof Junctions:** • Is the basic roof plan a simple rectangle (or square)? ❑ No ❑ Yes Sketch the plan on this page, including gables, dormers, skylights, junctions with walls,etc. • Where roof planes intersect, are the valley flashings and ridge caps in good condition? ❑ No ❑ Yes • Are gutters and fascias in good condition? ❑ No ❑ Yes • Where roofs and walls meet, is the junction waterproof? ❑ No ❑ Yes • Is there water marking on walls? ❑ No ❑ Yes	

Risk	Recommendations	GUIDE References
	• Explore the feasibility of carrying the setback structure through the floors below to firm bearing. • Evaluate the structure supporting the setback, and strengthen as necessary • Support masonry on steel supports (stainless or hot dipped steel) to replace wood. • Consider whether the masonry is in an isolated enough location to allow it to fall off without causing structural damage or injury.	p. 64
	• Carefully inspect roof and deck areas where they intersect with walls, other roofs, or terminate. These are locations where debris, as well snow and ice, build up, and are more exposed to the abrasion.	p. 66

	EARTHQUAKE EVALUATION	CHECKLIST B EVALUATING THE EXTERIOR
Item #	**Conditions to Check**	**Notes** **Property Address:** ____________
B4	**MATERIALS ON THE EXTERIOR**	
	❑ **Exterior Wall Finish:** • List the exterior finishes for each facade of the house: **Street:** ____________ **Rear:** ____________ **Left Side:** ____________ **Right Side:** ____________ • Main entry to house is on ____________ side of house. • Secondary entry to house is on ____________ side of house.	• Wood and stucco exterior finishes provide a limited degree of seismic resistance for exterior walls and cripple walls. However, without being built as braced walls, they are not adequate to resist strong earthquakes.
B4.1	❑ **Wood:** • Is any structural wood or wooden cladding spongy or crumbling? ❑ **No** ❑ **Yes** If yes, where: ____________ ____________	• Use a pointed instrument such as an ice pick to probe for wood decay.
B4.2	❑ **Masonry Veneer:** • Is there any brick, block or stone masonry? List the type of veneer and its location. Also indicate the approximate height of the masonry (for example, up 4 m from the ground, up 2 m along the south dormer). ____________ ____________	• Masonry is particularly susceptible to collapse in an earthquake. It is important to identify the extent to which its collapse may cause injury or property damage, and whether it will block emergency egress. • Cracks often indicate existing stresses in the building, which usually become areas of increased damage or failure during an earthquake.

Risk	Recommendations	GUIDE References
	• Upgrade the finish of exterior walls as per the recommendations in Section C of the *Guide* • Where the collapse of finishes such as masonry could pose a threat to occupant safety, either upgrade the strength of those finishes, remove them or construct a sheltered exit from the house designed to protect from falling debris.	
	• Replace decayed structural wood with pressure preservative treated material. • Ensure that the exterior cladding extends beyond the bottom of the sill plate and has been adequately nailed.	p. 68
	• Thoroughly inspect the veneer for cracks in the mortar joints or bricks. • When the veneer is located where its collapse may cause damage or injury, it should be reinforced or removed.	p. 68

	EARTHQUAKE EVALUATION	**CHECKLIST B EVALUATING THE EXTERIOR**
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________________
B4.3	❑ **Stucco:** • Are there any cracks in stucco? ❑ No ❑ Yes If so, where: ______________________ ______________________	• Stucco is particularly susceptible to damage in an earthquake, and can collapse. Identify the extent to which its spalling or collapse may cause injury or property damage, and whether it will block emergency egress. • Cracks often indicate existing stresses in the building which usually become areas of increased damage or failure during an earthquake.
B4.4	❑ **Exterior Foundation:** • What is the condition of the foundation walls around the house? **Street:** ______________________ **Rear:** ______________________ **Left Side:** ______________________ **Right Side:** ______________________	• Renovation or repair work which exposes foundations provides an opportunity for examination. Check for: • Crumbling concrete or masonry, • Crumbling mortar, • Cracks, chips or holes.
B4.5	❑ **Heavy Roof Loads:** • Is the roof finished in a heavy system such as slate, clay or concrete tile? ❑ No ❑ Yes • Is the house constructed in an area subject to heavy snow loads? ❑ No ❑ Yes • Does the snow pile up on some parts of the roof more than others? ❑ No ❑ Yes	• Heavy roof loads, whether building materials, snow, or ice place stress on a house at the location furthest from the ground. During a quake, the additional loads increases the stress the entire structure of the house must resist.

Risk	Recommendations	GUIDE References
	• Thoroughly inspect the stucco for cracks. • Where the veneer's collapse may cause damage or injury, it should be reinforced or removed.	p. 70
	• Examine the condition of materials and assess the seismic capability of the foundation. • Whenever contemplating an addition, ensure new foundations are seismically designed and constructed on firm bearing. • Replace portions of porches, decks, etc. which are resting on wood foundations with continuous concrete strip foundations or concrete post foundations. Section C of the *Guide* includes a specific discussion of foundations.	p. 70 p. 82
	• There are several methods to overcome hazards from roof loads. A simple approach is to avoid the use of heavy roofing materials. If heavy materials are used, the supporting roof structure should be engineered and roofing units must be thoroughly attached. • Ensure heavy roof finishes, or snow or ice, will not fall onto an exit pathway.	p. 72

	EARTHQUAKE EVALUATION	CHECKLIST B EVALUATING THE EXTERIOR
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________
B5	**APPENDAGES TO THE HOUSE**	
B5.1	❑ **Canopies, Porches and Decks:** • Are canopies, porches or decks part of the exit path from the house? ❑ **No** ❑ **Yes** • Do these structures sit on reinforced concrete foundations? ❑ **No** ❑ **Yes** • Are the foundations set below grade onto undisturbed subsoil? ❑ **No** ❑ **Yes** • Is there any bracing of structural elements below the deck level? ❑ **No** ❑ **Yes** • Are wood decks finished with plywood or spaced wood members? plywood thickness: ______________ wood member dimensions: ______________	• These elements often collapse in earthquakes. • Raised wood decks and porches are often built without any seismic resistance. They often lack proper foundations, bracing or hold-downs. • If these elements are not in an exit path, or threatening one in the event of their collapse, then upgrading may not be necessary, provided the home-owner accepts the likelihood of total collapse and loss of these elements in an earthquake. • Spaced wood members such as the 1 x 4's commonly used as nailing surfaces for shingles do not provide roofs with adequate seismic resistance. By contrast, well nailed plywood sheathing over rafters provides an excellent bracing effect as well as improving protection from elements such as collapsing chimneys.
B5.2	❑ **Roof-Mounted Elements:** • Are there any unusual elements on the roof, such as dish antennae or solar heating devices? ❑ **No** ❑ **Yes**	• Eccentric or heavy roof loads place extra stress on the entire structure.
B5.3	❑ **Masonry Chimneys:** • If they are present, what are their dimensions and where do they sit: ______________ • Other areas of concern: ______________ ______________	• Some experts believe falling masonry veneer and especially chimneys are the greatest potential cause of injury and death in an earthquake.
B5.4	❑ **Manufactured Metal Fireplace Chimneys:** • Are there metal braces? ❑ **No** ❑ **Yes**	

Risk	Recommendations	GUIDE References
	• If canopies, porches or decks are part of the exit path, they must be constructed to resist an earthquake and to protect people from falling debris. • **Foundations:** Confirm that the foundations are adequate for the loads. Construct of reinforced concrete placed on bearing soil, or other engineered design. • **Connections:** Ensure the appendage structure is securely connected to the main house. Ensure that the columns are of adequate size and are securely connected to the foundation and to the structure (beam/joist) above. Use engineered galvanized metal connectors. • **Bracing:** Add bracing to the open faces of the structures to provide stability. As a minimum, install X-bracing to top and bottom of each vertical post support. Refer to Item C1 and Items C8 in Section C for detailed information.	p.74 p.82 p. 126
	• Brace roof-mounted elements back to the main structure, ensuring the main structure is strengthened to accommodate the additional loads. • Strengthen adjacent roof and wall areas onto which the element might collapse, with the aim of preventing the collapsing other roofs or walls. • If collapse of the roof-mounted elements appears inevitable, consider removing them from their hazardous location.	p.74
	• If the chimney is not in use, remove it and cap off the hole through the roof. • If the chimney remains in use, remove as much of it as possible, preferably from the point where the fireplace narrows to the chimney, but at least from the roof line up. Replace with an insulated metal flue. Use the opportunity to improve the bracing of the areas through which the chimney passes.	p. 76
	• Examine the metal chimney's bracing. The chimney should have at least two braces to a pitched roof. Add braces as necessary.	p. 78

EARTHQUAKE EVALUATION

CHECKLIST B EVALUATING THE EXTERIOR

Item #	Conditions to Check	Notes Property Address: ______________________
B6	**OPENINGS IN THE HOUSE EXTERIOR**	
B6.1	❑ **Soft Storeys** • Are there large openings in the exterior walls (for picture windows, patio doors, garage doors, carports, outdoor covered areas)? ❑ **No** ❑ **Yes**	• Where exterior walls have large lengths of openings, the house may not successfully withstand seismic forces. 
B6.2	❑ **Corner Windows and Open Corners:** • Does the house have any corner windows? ❑ **No** ❑ **Yes** • Does the house have any open corners? ❑ **No** ❑ **Yes**	• Corners of houses experience great forces during earthquakes. Where corners are open or are windows (rather than solid walls), the threat of collapse is increased. 
B6.3	❑ **Openings in Walls - Basement Level:** • Approximately what percentage of the length of the <u>basement</u> walls have window, door or other openings in them? Street : _______% Left Side: _________% Rear: ________% Right Side: ________%	• To remain stable in an earthquake, a certain proportion of walls must be of braced construction. • Walls with large openings are inherently weaker than solid walls. • The 'soft' effect is increased when the open floor supports additional floors.
B6.4	❑ **Openings in Walls - First Floor Level:** • Approximately what percentage of the length of the <u>first storey</u> walls have window, door or other openings in them? Street : _______% Left Side: _________% Rear: ________% Right Side: ________%	• To remain stable in an earthquake, a certain proportion of walls must be of braced construction. • Walls with large openings are inherently weaker than solid walls. • The 'soft' effect is increased when the open floor supports additional floors or heavy loads above.

Risk	Recommendations	GUIDE References
	• Consider reducing the length of opening, by infilling them with solid walls and supporting structure, to achieve lateral stability. • Where infill is not feasible or desirable, build a rigid frame around the openings and seismically connect to the adjacent structure. The adjacent structure will need to be strengthened to accommodate the new loads.	p. 78
	• Consider modifying the corner opening configuration to provide a seismically resistant supporting structure in all corners. • Where infill is not feasible or desirable, build a rigid frame around the corner element. The adjacent structure will need to be strengthened to accommodate the new loads.	
	• Calculate the percentage of wall perimeter that should be braced, using the recommendations in the *Guide* found in Section C, Evaluating the Interior Structure.	
	• Calculate the percentage of wall perimeter that should be braced, using the recommendations in the *Guide* found in Section C, Evaluating the Interior Structure.	

EARTHQUAKE EVALUATION		CHECKLIST B EVALUATING THE EXTERIOR
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________
B6.5	❑ **Openings in Walls - Second Floor Level:** • What percentage of the length of the second storey exterior walls have window, door or other openings in them? Street : ______% Left Side: ________% Rear: _______% Right Side: _______%	• If the house is 1-1/2 storeys (living space within the roof volume), calculate the percentage of openings using the length of the roof plane rather than length of wall.
B6.6	❑ **Openings in Walls - Third Floor:** • Approximately what percentage of the length of the third storey walls have window, door or other openings in them? Street : ______% Left Side: ________% Rear: _______% Right Side: _______%	• If the house is 2-1/2 storeys (living space within the roof volume), calculate the percentage of openings using the length of the roof plane rather than length of wall.
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	

Risk	Recommendations	GUIDE References
	• Calculate the percentage of wall perimeter that should be braced, using the recommendations in the *Guide* found in Section C, Evaluating the Interior Structure.	
	• Calculate the percentage of wall perimeter that should be braced, using the recommendations in the *Guide* found in Section C, Evaluating the Interior Structure.	

EARTHQUAKE EVALUATION — CHECKLIST C: EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes **Property Address:** ______________
C1	**FOUNDATIONS**	
C1.1	❑ **Foundation Types** • What type of foundation does the house appear to have? ❑ Continuous ❑ Mat ❑ Drilled pier or caisson-pile ❑ Composite (describe): ______________ ______________	• Many houses with foundations that appear to match these are not engineered and do not contain the necessary reinforcing steel and thus may not provide sufficient seismic resistance.
C1.2	❑ **Footing Types:** ❑ No footing ("I" shaped foundation wall) ❑ Continuous spread footing (inverted "T") ❑ Rectangular grade beam ❑ Trapezoidal grade beam ❑ Slab-on-grade with thickened edges ❑ Other: ______________	• It may be difficult to find out this information. However, there may be areas, such as a basement door, where footings are visible or accessible without too much effort. • Also, municipal authorities may have records of this and other foundation details.
C1.3	❑ **Foundation Bearing:** • Does the foundation rest on rock or stiff soils? ❑ **No** ❑ **Yes** ❑ **Can't tell** • Are there continuous foundations under all bearing walls inside or outside the perimeter walls? ❑ **No** ❑ **Yes** ❑ **Can't tell** • Are there continuous foundations under perimeter walls? ❑ **No** ❑ **Yes** ❑ **Can't tell** • Are there concrete piers set on continuous footing and into grade? ❑ **No** ❑ **Yes** ❑ **Can't tell**	• A 'YES' response to these checklist items is favourable to the seismic resistance of the house, although columns supported on foundations should be laterally braced.
C1.4	❑ **Condition of Foundations:** • Do foundation walls, footings, or piers appear crumbly or have significant cracks? ❑ **No** ❑ **Yes** ❑ **Can't tell**	• Scrape a screwdriver or key across the foundation, and if the concrete or mortar crumbles away easily, it is very likely to fail during an earthquake.
C1.5	❑ **Masonry Foundations** ❑ Concrete block walls or piers ❑ Brick masonry walls or piers ❑ Rubble masonry walls or piers (for example, stone) ❑ Steel reinforced ❑ Unreinforced ❑ Can't tell	• Masonry often represents a major source of failure in an earthquake, especially if not steel reinforced. • Mortar is generally not strong enough to keep masonry units together in an earthquake.

Risk	Recommendations	GUIDE References
1 2 3	For each checklist item that applies to the house, assess the relative risk of the existing condition and assign a risk factor: 1 = Possible Loss of Property; 2 = Possible Loss of Shelter; 3 = Possible Loss of Life.	
	• If assessment of the foundations indicates they are not adequate, consult a structural engineer and, if necessary, provide temporary seismic support to the affected structures.	
	• Where a house has a continuous foundation, the general upgrade recommendations regarding cripple walls, foundation-to-sill, etc., will apply. • Where a house has a mat or slab-on-grade foundation, the recommendations regarding fastening the sill plate to the foundation should apply. • Where a house has drilled pier/caisson or composite foundations, the advice of a structural engineer should be sought.	p. 84
	• If foundation walls have no footings, add footings with reinforcing steel during any associated renovation work, based on a structural engineer's recommendations. • If there are footings that are not reinforced, excavate around and add a new steel reinforced footing below the first, to a structural engineer's recommendations.	
	• Foundations that are not bearing on rock or stiff soils should be reviewed by a structural engineer. • Where it is apparent that footings are not present or not continuous, the foundations should be reviewed by a structural engineer. • Where appendages such as porches, decks, etc., are set on concrete piers, the bracing recommendations of the *Guide* may suffice. • Where a portion or all of the principal house structure sits on concrete piers, the advice of a structural engineer should be sought.	
	• Foundations in poor condition or poorly constructed are seldom adequate and should usually be replaced. • Existing piers that rest on finished grade should be reset onto firm bearing with the bulk of the pier below the surface.	
	• It may be necessary to replace masonry foundations with steel reinforced foundations. Consult a structural engineer if masonry foundations are prevalent.	p. 88

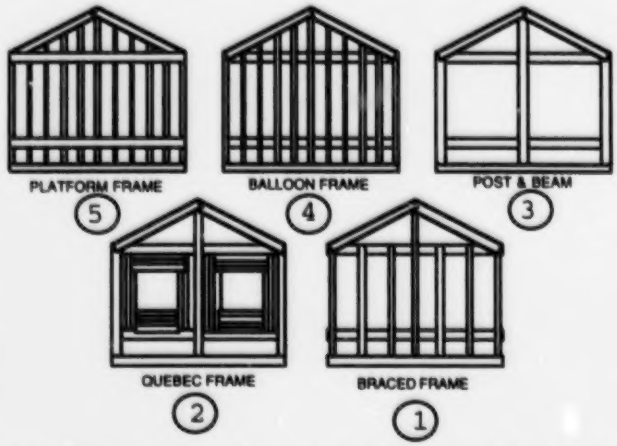
	EARTHQUAKE EVALUATION	CHECKLIST C EVALUATING THE INTERIOR STRUCTURE
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________
C1.6	❑ **Concrete Foundations:** • Continuous concrete walls ❑ Steel reinforced ❑ Unreinforced ❑ Can't tell	• Unreinforced concrete foundations will experience a high degree of failure during significant earthquakes, particularly in soils of soft clay and on slopes.
C1.7	❑ **Foundation Posts (Columns):** • Wood posts Do they appear decayed or have major cracks? ❑ **No** ❑ **Yes** Size of wood posts: ______________ • Steel Posts Type of steel posts: ______________ Size of steel posts: ______________	• The connections between the posts and the structure above and below are critical to transfer or share loads. • Wood posts less than 140 x 140 mm (6" x 6") are generally too slender to be of value. • Adjustable steel jacks are often used as structural supports for major beams. • Steel posts of 75 mm (3") dia. may be of sufficient dimension, depending on connection details.
C1.8	❑ **Dimensions of Concrete Foundation:** • Thickness of foundation walls: ______________ • Does the foundation in the basement extend: ❑ up to the joists of the floor above? ❑ part way up the wall, with short wood studs above?	• Concrete foundation walls less than 200 mm (8") thick, especially without reinforcing steel, will provide limited resistive value in an earthquake. **Full Height Foundations:** • Where the floor structure rests directly on the foundation walls, the connections to the foundations are critical and difficult. **Partial Height Foundations:** • During earthquakes, houses often fail where short wood-framed walls (called a cripple wall) connect the foundation walls to the floor diaphragm above.
C1.9	❑ **Crawl Space:** • Does the house have a crawl space? ❑ **No** ❑ **Yes** • Clear height to underside of floor structure above: ______________(dimension)	• Crawl space is often built using cripple wall construction having very poor seismic resistance. • Crawl space often has limited access, making seismic upgrades difficult.

Risk	Recommendations	GUIDE References
	• Set anchor bolts, hold-downs and other concrete penetrations at least 50% deeper in suspected unreinforced concrete. • If concrete is at all soft use epoxy set anchor bolts or other steel connectors.	p. 90
	Posts (Columns): • Sizes and connections to adjacent structure should be designed by a structural engineer. • Where possible, add lateral bracing to stabilize free-standing posts. **Wood Posts:** • Upgrade wood posts throughout to a minimum of 140 x 140 mm (6" x 6"). • Connect posts to structure above and below with steel connectors. **Steel Posts:** • Ensure that they are integrated with surrounding wood frame by secure connections to structural elements above and below, and adjacent wall structures. • Replace adjustable posts with permanent, continuous posts.	p. 114
	General Foundation Upgrading: • Whenever foundation walls supporting lateral braced frame walls are exposed, add reinforcing. **Full Height Foundations:** • Add steel connectors to secure the sill plate, rim joist, and floor diaphragms to the foundation wall. Refer to Item C8 for a detailed description. **Partial Height Foundations:** • Where a short wood-framed cripple wall connects the foundation wall to the floor structure above, detailed bracing and connections are required. For details of laterally braced walls and structural connections, refer to Items C3, C4 and C8.	p. 106 p. 114 p. 126 p. 102
	• Refer to recommendations for foundations, sill plates, cripple walls, and structural connections (located in Chapter 4, Section C).	p. 82 p. 102 p.128 p. 126

EARTHQUAKE EVALUATION	CHECKLIST C EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes **Property Address:** ____________________
C2	**WOOD-FRAME SYSTEMS**	
C2.1	❑ **FRAME TYPES:** • Which of the following frame type describes the construction of this house? ❑ Braced Frame - (historical system) ❑ Quebec Frame - (seldom seen elsewhere) ❑ Balloon Frame - (fairly common pre-1940) ❑ Post and Beam ❑ Platform Frame ❑ Composite • First Floor (Describe): ____________ • Second Floor (Describe): ____________ • Third Floor (Describe): ____________ • Roof (Describe): ____________	• Different wood frames react very differently to seismic loads. Each has advantages and disadvantages. Refer to the *Guide* for details. • The most challenging structure to analyze is the composite, where parts of the house are constructed using different frame systems. With this type, it may be necessary to consult a structural engineer, because the *Guide* does not adequately deal with the complexities of multiple, non-integrated systems.

C3	**CRIPPLE WALLS**	
C3.1	❑ **Cripple Wall Construction:** • Are the cripple wall studs in good condition with minimum 38 x 89 mm (2" x 4") studs at maximum 400 mm (16" centre to centre) spacing? ❑ **No** ❑ **Yes**	• Check quality of studs, look for checks, cracks, large knots in the wood and decay or insect damage.

Risk	Recommendations	GUIDE References
	 Simple diagrams comparing gable end wall construction of typical Canadian framing systems.	p. 94

	A very high proportion of earthquake damage to wood-frame houses is from structural failure of cripple walls. To provide adequate seismic resistance, the cripple wall must be laterally braced, must be firmly connected to the foundation below and the floor above, and the building materials must be in good condition.	
	• Replace any cripple wall studs that are not in good condition. • Add cripple studs to provide minimum 400 mm (16") centre to centre spacing. • Consider using pressure preservative treated lumber for any required replacement or supplementary cripple wall framing members.	p. 102

Item #	Conditions to Check	Notes Property Address: ____________
C3.2	❑ **Sheathing Materials:** • What is the finish material and sheathing on the ***outside*** face of the cripple wall studs? Materials (describe): ____________ ____________ Materials - thickness ____________ Nailing ________ centre to centre edges ________ centre to centre field • What is the sheathing material on the ***inside*** face of the cripple wall studs? Materials (describe): ____________ ____________ Materials - thickness ____________ Nailing ________ centre to centre edges ________ centre to centre field	• Sheathing consisting of horizontal boards or thin plywood (less than 9 mm [3/8"]) provides little seismic resistance. Where there is existing sheathing, it is difficult to verify nailing patterns, which are often inadequate. • To provide reasonable resistance to earthquakes, sheathing of plywood is most desirable. Other applications such as diagonal bracing, diagonal boarding, or non-plywood types of panel products provide less lateral bracing strength.

C4	SUPPORTING WALLS	
C4.1	❑ **Laterally Braced Walls:** • How are the supporting walls at various levels in the house braced, if at all? ❑ No apparent bracing ❑ Can't tell ❑ Horizontal boards ❑ Diagonal boards ❑ Diagonal braces ❑ Fibreboard ❑ Plywood ❑ Other (describe) ____________ ____________	

Risk	Recommendations	GUIDE References
	• Seismically connect cripple walls to the foundations below and the floor diaphragm above. • Upgrade the lateral bracing of the cripple wall on either the interior or exterior face. (Refer to the Item C4 for methods available). • Where the inside face of a cripple wall is sheathed, either drill ventilation holes into the resultant cavities between each stud or construct it as a standard insulated exterior wall complete with air and vapour barriers. The recommendations apply where the cripple wall forms either a crawl space or a basement.	p. 108

	The considerations and procedures associated with this aspect of seismic upgrading are complex. Refer to Item C4 for detailed information	p. 106
	• Supporting walls are designed to distribute and carry the weight (vertical forces) of the house to the ground. Earthquakes can generate both horizontal and vertical forces of large magnitude. These chaotic motions must be successfully resisted by the supporting walls if the house is to survive. Laterally braced walls are used to provide a more rigid and more direct path for the transfer of the forces in the house with the foundation. • Assess the strength of each wall in each level of the house as regards to lateral bracing. Decide how to upgrade supporting walls consistently with the specific characteristics of the house described in the *Guide* and any renovations under considerations. (*Guide* elements include geometry, foundation, materials, openings, connections, soils, and others.) • Upgrade the lateral bracing of the supporting walls on either the interior or exterior face. (Refer to Item C4 for methods available).	p. 108

Item #	Conditions to Check	Notes Property Address: ___________________________
	• For each level in the house, note the type(s) of bracing and nailing pattern if they can be determined and record below: **Basement level** ___________________________ **Main (First) level** ___________________________ **Second level** ___________________________ **Third level** ___________________________ **Attic level** ___________________________ • Draw a plan of each floor, illustrating the walls and their bracing condition(s).	
C4.2	❑ **Alignment of Structure:** • Do the apparent structural bearing walls of each floor align with walls of the floor above? • If there is an offset between bearing walls, how much is it and where? ___________________________ ___________________________	• Where the structure is not vertically aligned, and misalignments exceed 300 mm (12"), a structural engineer's opinion should be sought regarding the seismic implications, as well as recommendations for improvement.
C4.3	❑ **Exterior Materials:** • What is the finish material and sheathing on the ***outside*** face of the exterior walls? Materials (describe) : ___________________________ ___________________________ Materials - thickness ___________________________ Nailing _______ centre to centre edges _______ centre to centre field	• Most sheathing and finish materials provide some structural value for lateral bracing; however the strength is dependent on the nature and condition of such things as the materials, thicknesses, nailing patterns and workmanship. • The composition of the support walls in existing houses may be difficult to determine. If any portions of the framing behind the finishes are accessible for inspection (for example, furred out spaces and duct spaces), check to verify wall construction.
C4.4	❑ **Interior Materials:** • What are the finish materials on the ***inside*** face of the exterior walls? Materials (describe) : ___________________________ ___________________________ Materials - thickness ___________________________ Nailing _______ centre to centre edges _______ centre to centre field	• Plaster and drywall can provide some structural value for lateral bracing, if correctly installed and in very good condition. • The composition of the support walls in existing houses may be difficult to determine. If any portions of the framing behind the finishes are accessible for inspection (for example, furred out spaces and duct spaces), check to verify wall construction.

Risk	Recommendations	GUIDE References
	• When the structural walls are not aligned, but misalignment appears slight (less than 300 mm [12"]): • Use steel connectors to connect the structure of the lower wall to the floor structure above it. • Using typical clues like doubled joists or blocking, identify the location of the wall structure above. • Use steel connectors to connect the structure of the upper wall to the floor structure below it.	p. 106
	• Provide laterally braced walls at the perimeter of the house, distributed equally along all the exterior walls in a symmetrical pattern (refer to Item C4 of the *Guide* for more detailed information). • Ensure that each floor and each storey's supporting walls are well connected to the next element above and below. This is accomplished by: • Using steel connectors on the inside between horizontal and vertical elements at the perimeter walls (where the inside frame is accessible) or, • Using steel connector straps applied to the exterior of the house, either fastened to the framing where it may be exposed on the outside, or fastened through the exterior finish.	p. 106
	• For further discussion on interior finishes, refer to item D6.	p. 166

EARTHQUAKE EVALUATION

CHECKLIST C
EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes Property Address: ______________________
C5	**COLUMNS**	
C5.1	❑ **Wood Columns (Posts):** • Check the condition of the wood in the columns, especially those exposed to weather, in contact with concrete or the earth. • Determine how the columns are connected to adjacent structures, including sill plates, floor structures, joists and beams above.	• Columns (posts) are frequently used in crawl spaces and basements to support the floor above. They are also commonly used to support decks or carports with a living space above. • It is often necessary to remove finish materials on columns or surfaces around the column to assess conditions.

C6	**CORNERS**	
C6.1	❑ **Corner Framing:** • Are the corners of the house constructed as walls without any openings? ❑ **No** ❑ **Yes** • Are the walls at corners continuous from eaves to foundation, without corner cantilevers, jogs, bays or windows? ❑ **No** ❑ **Yes**	• Corners at the exterior of houses should be constructed as laterally braced walls and firmly connected to structures above and below.

C7	**FLOOR AND ROOF DIAPHRAGMS**	
C7.1	❑ **Floor:** • What is the floor structure: Materials ______________________ Sheathing Materials ______________________ Thickness ______________________ Nailing __________ centre to centre edges ______________ centre to centre field	• Older houses usually have subfloors (the rougher material below the finished floor material) consisting of diagonal tongue and groove boards, which have some seismic value. Newer house subfloors are usually plywood or oriented strand board (OSB), which have improved seismic resistance.
C7.2	❑ **Roof:** • What is the roof sheathed with: Roof Materials ______________________ Sheathing Materials ______________________ Thickness ______________________ Nailing __________ centre to centre edges ______________ centre to centre field	• Spaced boards used under wood shingles/shakes and tiles are of minimal value to the structure's earthquake resistance. • Solid sheathing products, when correctly nailed to the supporting structure, generally provide adequate seismic resistance. They are normally of sufficient thickness and strength because of the load requirements for snow, wind, and roof materials.

Risk	Recommendations	GUIDE References
	• If decay and insect damage are found, the cause should be determined and corrected as part of the column repair. • All damaged wood should be removed. Remaining wood and replacement wood should be treated with a preservative. • Install engineered steel connectors at head and foot of columns - these must connect the column directly to the supporting structure with no extraneous material in the connection.	p. 114
	• If walls are limited or absent from corners, consult a structural engineer. • Add additional wall structure at corners or upgrade existing framing to provide increased lateral support. Refer to discussion of laterally braced walls in Item C4 for methods available. • Install steel ties to connect the wall and floor systems and to anchor corner columns.	p. 116 p. 106
	• Where older houses have diagonal boards as their subfloor, refer to the upgrading recommendations regarding connecting floor joists to subfloors with metal connectors.	p. 120
	• Use opportunities associated with roof maintenance or renovations to substitute plywood sheathing for spaced boards (use a ventilation mat when roofing with wood shakes or shingles). • Nail panel sheathing as recommended for shear walls. (For nailing pattern refer to Appendix C). • Where a partial roof upgrade is contemplated, enlarge replaced roof areas so that they extend to roof edges, allowing the upgraded roof structure to be tied into supporting walls or gables. • Where accessible, add anchorage from rafters and trusses to the supporting wall structure. Upgrade gable walls to create braced walls.	p. 124

Item #	Conditions to Check	Notes Property Address: ________________
C7.3	❑ **Large Openings in Diaphragm Structure:** • Other than regular stair openings and openings for elements such as chimneys and furnace flues, are there openings between floors larger that 1 m² (10 ft²)? ❑ **No** ❑ **Yes** If so, describe dimensions and location: **Dimensions:** ________________ **Location:** ________________ **Sketch**	• Large openings through floors, such as double height entry foyers or roofs for large skylights, cause stress around the openings and in any adjacent "thin" areas of diaphragm structure. 

Risk	Recommendations	GUIDE References
	• Upgrade horizontal and vertical bracing around openings and in adjacent areas.	p. 78

EARTHQUAKE EVALUATION

CHECKLIST C
EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes **Property Address:** ______________________
C8	**STRUCTURAL CONNECTIONS**	
C8.1	❑ **Sill Plate:** • Is the wood sill plate damaged or decayed? ❑ **No** ❑ **Yes** • Do the joists of the floor above the basement sit directly on top of concrete? ❑ **No** ❑ **Yes** • Is the existing wood sill plate at least 38 mm (1.5") thick? ❑ **No** ❑ **Yes**	• Look for dry, spongy and crumbling portions of sill plate, as well as for major cracks or splits in the wood. Use an ice pick or similar instrument to probe the sill plate wood. • Some houses are built with joists sitting directly on foundations. The connection between the house frame and foundation are critical.
C8.2	❑ **Sill Plate Connections to the Foundation:** • Is the sill plate bolted to the foundation? ❑ **No** ❑ **Yes** • If so, do the bolts have washers and nuts? ❑ **No** ❑ **Yes** • Do the nuts turn easily with a wrench? ❑ **No** ❑ **Yes** • Do the bolts turn at all when twisted with a wrench? ❑ **No** ❑ **Yes** • Are the bolts at least 12 mm (1/2") diameter? ❑ **No** ❑ **Yes** • Do they penetrate into the foundation? ❑ **No** ❑ **Yes** ❑ **Can't tell** • What is the approximate spacing between bolts? ______________________ • What is the distance of the anchor bolts from the corners of the walls? ______________________ • How close are bolts placed to the ends of each individual piece of sill plate? ______________________	• It is imperative that the connections between framing and foundations be secured at regular intervals. Many houses have sill plates resting on top of foundation walls without sufficient (or any) connection.

Risk	Recommendations	GUIDE References
	Damaged Sill Plate: • Replace damaged or decayed portions of the sill plate with new, preservative-treated wood with dimensions of at least 36 x 140 mm (2" x 6"). Determine and correct the cause of damage before doing repairs. **No Sill Plate or Plate too Thin:** • Use floor joist steel connectors to individually connect joists to the foundation and install solid blocking between joists at the ends.	p. 128
	Insufficient Anchor Bolts: • Where the sill plate has no anchor bolts or an insufficient number, connectors must be added. Expansion bolts or epoxy set systems can be used to set new anchor bolts. • When access to the top of the sill plate is difficult (making the installation of new anchor bolts difficult), specialized engineered steel connectors can be installed to anchor the wood frame to the foundation. **Anchor Bolt Connections Incomplete:** • Ensure that all anchor bolts have washers and nuts and are tightened. • In lieu of washers, consider larger bearing plates designed to further spread the load from the bolt through the sill plate. **Undersized or Damaged Bolts:** • Where existing anchor bolts are less than 12.7 mm (1/2") diameter, appear corroded or damaged, remove and replace with new anchor bolts or engineered connectors. **Location (Spacing) of Adding Anchor Bolts:** • Locate anchor bolts within 200 mm (8") of the ends of each individual piece of sill plate. Each piece of sill plate should have at least two anchor bolts. • Ensure that bolts are spaced maximum 2.0 m (6.5') centre to centre for single-storey houses and 1.2 m (4') centre to centre for houses of two-storeys or more. **Inaccessible Sill Plate:** • Where access to anchor bolts (or proposed supplementary bolt locations) is not possible from the interior of the house, cut into the exterior wall from the exterior, above the sill plate line, to allow investigation and upgrading from the outside.	p. 130

CHECKLIST C
EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes Property Address: ______________
C8.3	❑ **Sill Plate Connections to the Wood Frame:** • Do the joists of the floor diaphragm sit on top of wood sill plates? ❑ No ❑ Yes • Does the bottom plate of the cripple walls (or stud walls) sit on top of wood sill plates? ❑ No ❑ Yes • Is the floor diaphragm connected to the inside face of the foundation (ledger connections)? ❑ No ❑ Yes	
C8.4	❑ **Column Connections:** • How are columns in the structure affixed at their head? ❑ No apparent connection ❑ Nailed directly to concrete or wood ❑ Nailed using a steel "column cap" ❑ Bolted using a steel "column cap" ❑ Other (Describe) ______________ ______________ • How are columns in the structure affixed at their base? ❑ No apparent connection ❑ Nailed directly to concrete or wood ❑ Nailed using a steel "column base" ❑ Bolted using a steel "column base" ❑ Other (Describe) ______________ ______________	• Column connections to the structure at both the head and base are a major point of seismic weakness that are highly prone to failure during earthquakes.
C8.5	❑ **Joist and Beam Connections:** • How are floor joists connected to beams or walls? ❑ Metal hangars ❑ Nails alone ❑ Blocking and nails ❑ Other (Describe) ______________ ______________ • Do joists with a clear span of 2.4 m (8') or more have cross bridging or solid blocking at the approximate mid span? ❑ No ❑ Yes ❑ Can't tell • How are beams connected to the adjacent structure? ❑ Metal hangars ❑ Nails alone ❑ Blocking and nails ❑ Other (Describe) ______________ ______________	• Appropriately chosen and installed engineered steel joist and beam hangars provide at least twice the seismic resistance as traditional blocked and nailed connections.

Risk	Recommendations	GUIDE References
	Diaphragm to Sill Plate Connections: • Use L-shaped steel connectors to fasten diaphragm joist (and header joist or blocking) to sill plate. The same connectors can also be used to tie the joist to the blocking and headers. **Cripple or Stud Wall Connection to Sill Plate:** • Install additional wood blocking to reinforce the connection between the studs and the sill plate. Nail blocking, matching the dimensions of the framing members, horizontally between the studs on top of the plate. • If blocking is not adequate or additional strength is desired, install engineered steel connectors to attach studs to the sill plate. • Install engineered steel hold-downs near the corners of the foundation. Hold-downs are fastened to the wall frame and bolted through the sill plate into the foundation. **Ledger Connections:** • Ledger connections are discussed in Item C8.6.	p. 138 p. 148
	Existing Nailed Only Connection between Column and Adjacent Structure: • Add a connection, either by temporarily supporting the beam and inserting steel column connectors, or by fastening the column to the adjacent structure with engineered steel angles. **Existing Nailed or Bolted Steel Column Head or Base Connector:** • Verify the specified fastening and strength of existing connectors and upgrade as required to adequately resist seismic loads. **Stabilize Column :** • Consider stabilizing columns with installation of cross bracing or construction of laterally braced walls.	p. 142
	Exposed Joists and Beams: • Take the opportunity to upgrade connections using engineered steel joist and beam hangars to connect wood structural elements that are exposed as a part of renovations.	p. 146

EARTHQUAKE EVALUATION

CHECKLIST C
EVALUATING THE INTERIOR STRUCTURE

Item #	Conditions to Check	Notes **Property Address:** ______________
C8.6	❑ **Ledger Connections:** • Are joists of the floor diaphragms supported on ledgers? ❑ **No** ❑ **Yes** ❑ **Can't tell** • How are the ledgers connected to supporting walls? ❑ Anchor bolts at approx. ______________ centre to centre ❑ Other (Describe) ______________ ______________	• Both diaphragm to ledger and ledger to structure connections are frequently insufficient to resist strong earthquakes. • Ledgers are used in balloon or braced framing systems, associated with older houses.
C8.7	❑ **Floor Diaphragm and Wall Connections:** • Are there any devices, other than nails, used to connect floor diaphragms to walls above and below? ❑ **No** ❑ **Yes** ❑ **Can't tell**	• To maintain the continuous force path through the structure, the diaphragms must be adequately connected to the supporting walls.
C8.8	❑ **Roof Diaphragm to Wall Connections:** • How is the roof structure connected to the wall structure below? ❑ Metal hangars ❑ Nails alone ❑ Blocking and nails ❑ Other (Describe) ______________ ______________	• Roof diaphragm connections to supporting walls help tie the house together at the top and are important in providing a continuous path for transferring seismic forces.
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	

Risk	Recommendations	GUIDE References
	Reinforce Ledger-to-Joist Connections: • Upgrade the connection between the joist of the floor diaphragm to the supporting ledger using steel connectors. This condition is often similar to the diaphragm to sill plate connections discussed in Item C8.3. **Reinforce Ledger-to-Wall Connections:** • Verify adequate anchorage of ledgers to their supporting walls. Upgrade connection of ledger to wall using additional anchors as described in Item C8.2.	p. 148 p. 138 p. 130
	Where Exterior Framing Is Exposed: • Install steel strap ties at a regular spacing on exterior framing. Ties span the floor diaphragm and are nailed to the wall framing above and below. • Where possible, install hold-down connectors at the corners of the house to improve the transfer of forces at these critical locations.	p. 150
	• Provide continuous (freeze) blocking between structural roof members, but maintain venting to the insulated roof space. • Connect roof structure to the double plates of the supporting walls using steel connectors.	p. 152

EARTHQUAKE EVALUATION — CHECKLIST D: EVALUATING THE CONTENTS

Item #	Conditions to Check	Notes **Property Address:** ______________
D1	**FURNITURE**	
D1.1	❑ **Tall Furniture:** • What rooms contain tall furniture such as bookcases, china cabinets, "high-boy" dressers? ______________ • Is the furniture located such that it may fall on beds, couches or chairs? ❑ **No** ❑ **Yes**	• Any tall furniture with a narrow base will fall over in an earthquake. • It is prudent to consider what the furniture and its contents might fall upon if they topple over.

Item #	Conditions to Check	Notes
D2	**APPLIANCES**	
D2.1	❑ **Kitchen Appliances:** • Is the refrigerator located near work or seating areas or adjacent to the major path to an exit? ❑ **No** ❑ **Yes** • Does the refrigerator move easily ? ❑ **No** ❑ **Yes** • Are there any gas-fired appliances? ❑ **No** ❑ **Yes** If so, list them: ______________	• Refrigerators are a hazard during a quake because of their tendency to move or fall over. • Severed connections between appliances and gas line cause loss of use, and potential of fire and explosion.
D2.2	❑ **Wood Burning Stoves:** • Are there wood burning stoves in the house? ❑ **No** ❑ **Yes** If so, list them: ______________	
D2.3	❑ **Air Conditioners:** • Are there any air conditioners installed in the house? ❑ **No** ❑ **Yes** If so, where: ______________	• Air conditioners are heavy bulky appliances that can do severe damage to the building and injury to people during an earthquake.

Risk	Recommendations	GUIDE References
1 2 3	For each checklist item that applies to the house, assess the relative risk of the existing condition and assign a risk factor: 1 = Possible Loss of Property; 2 = Possible Loss of Shelter; 3 = Possible Loss of Life.	

	• Fasten tall furniture along top and sides to studs in walls. • Arrange the internal layout of rooms so that falling items are not located where people may be resting when an earthquake strikes. • Arrange the furniture in rooms so that falling contents or furniture itself does not block the path of exit.	p. 160

	• Reduce the tendency of large appliances to move during an earthquake by securing to adjacent surfaces or placing them on non-skid pads. • Anchor gas-fired appliances to the floor or wall.	p. 160
	• Anchor stove pipes to the flue exit. • Secure each segment of stove pipe together. • Provide a support brace to the wall to prevent lateral movement. • Anchor legs of the stove to the building structure.	p. 160
	• Preferably locate any air conditioner at ground level outside the house. If located in windows or on roofs, secure to the building structure. Consult a structural engineer or the manufacturer's engineer for assistance.	p. 160

EARTHQUAKE EVALUATION	**CHECKLIST D EVALUATING THE CONTENTS**

Item #	Conditions to Check	Notes Property Address: ____________
D3	**STORED AND DISPLAYED ITEMS**	
D3.1	❑ **Books:** • Are there heavy books stored on high shelves? ❑ No ❑ Yes If so, where? ____________	• Falling books are a common occurrence during earthquakes.
D3.2	❑ **Dishes and Glassware:** • Where are dishes and glassware stored? ____________ • Are storage cabinets locked or latched? ❑ No ❑ Yes ❑ Some Which are not: ____________	• Damage and injury occurs when objects fall out of the storage cabinet.
D3.3	❑ **Displayed Items:** • Is there any artwork or other objects hung? ❑ No ❑ Yes If so, where: ____________	• Pay particular attention to heavy objects on walls and pictures with glass or heavy frames.

D4	**LIGHTING AND OTHER ELECTRICAL FIXTURES**	
D4.1	❑ **Electrical Fixtures:** • Are there ceiling mounted track lights, fluorescent lights or fans? ❑ No ❑ Yes List them: ____________ • Are ceiling mounted fixtures equipped with safety cables? ❑ No ❑ Yes Which? ____________	• Damage to electrical service and fixtures could occur because of structural movement. • Fixtures may be torn from their mountings causing direct injury, damage to wiring could cause fire.

Risk	Recommendations	GUIDE References
	• Arrange large books and other bulky items on lower shelves. • Retain objects on the shelves by installing a bar or wire across the shelves. • Securely anchor shelves to the house structure.	p. 162
	• Provide a type of latch that will keep cabinet doors closed during an earthquake (remember, the contents of the cabinet will push against the doors). This approach can also be used for canned goods.	p. 162
	• Attach heavy objects to the house structure with threaded hooks to the wall studs. • For lighter objects, use normal but oversized "nail plus hook" hangers and close the open hook so the hanger wire cannot out come. • Consider replacing glass over pictures with plexiglass.	p. 162

	• Check the condition of electrical wiring. • Where possible, ensure that the wiring is stapled to the frame of the house (refer to Canadian Electrical Code for specific requirements). • Securely fasten ceiling fans and light fixtures to the frame of the house. Install safety cable for fixtures that represent a special hazard.	p. 162

CHECKLIST D
EVALUATING THE CONTENTS

Item #	Conditions to Check	Notes **Property Address:** ______________
D5	**BUILDING SERVICES AND EQUIPMENT**	
D5.1	❑ **Water Lines:** • Are water lines adequately supported throughout the house? ❑ **No** ❑ **Yes**	• Rupture of a water line can cause extensive interior water damage.
D5.2	❑ **Gas Lines:** • Are gas lines adequately supported between the point of entry and appliances served? ❑ **No** ❑ **Yes**	• A broken gas line will make appliances unusable and could lead to explosion or fire.
D5.3	❑ **Waste Lines:** • Are waste lines supported both within the framing system and underground? ❑ **No** ❑ **Yes**	• Rupture of a waste line can cause extensive interior damage.
D5.4	❑ **Water Tanks:** • Is the water tank located in an egress pathway? ❑ **No** ❑ **Yes** • Is the hot water tank strapped to the adjacent structure? ❑ **No** ❑ **Yes** How? ______________	• Water heaters are very vulnerable during an earthquake. They may move or fall over, which can break the water lines, or tear out the gas line or the electrical wiring, creating a major safety hazard.
D5.5	❑ **Furnaces and Boilers:** • Is the furnace/boiler located in an egress pathway? ❑ **No** ❑ **Yes** • Is the furnace/boiler seismically strapped to the adjacent structure? ❑ **No** ❑ **Yes** How? ______________	• The conditions affecting furnaces and boilers are similar to those that affect hot water tanks.

Risk	Recommendations	GUIDE References
	Refer to Section A, Evaluating the Property for information regarding the utilities coming onto the property.	
	• Water lines should be supported every 1.2 m (4 ft). • Support may consist of: a line being installed through a hole in a structural member such as a stud or joist; a clamp attached to a structural member. Refer to local authorities for current rules.	p. 164
	• A connection designed to flex should be installed between the appliances and the point where the rigid pipe is attached to the structure. • Gas lines should be supported every 1.2 m (4 ft). See comments on water lines above regarding appropriate support measures.	p. 164
	• Waste lines should be supported every 1.2 m (4 ft). See comments on water lines above regarding appropriate support measures.	p. 164
	• Reduce the hazard by securing the tank to the floor with bolts or strapping it to an adjacent wall. • Refer to Appendix C for a detailed explanation of methods for securing water tanks.	p. C-20 p. 166
	• Reduce the hazard by securing the appliances to the building structure and using flexible service connections. • Refer to Appendix C for a detailed explanation of methods for securing water tanks as a guide for these types of equipment.	p. C-20 p. 166

	EARTHQUAKE EVALUATION	CHECKLIST D EVALUATING THE CONTENTS
Item #	**Conditions to Check**	**Notes** **Property Address:** ______________________
D6	**INTERIOR FINISHES**	
D6.1	❑ **Plaster:** • Are plaster walls or ceilings in good condition? ❑ **No** ❑ **Yes** If not, where: ______________________	• Plaster finishes, especially if in poor condition, present a hazard to occupants. • Upper floor bedrooms and service rooms often have lesser quality plaster.
D6.2	❑ **Drywall:** • Are there any walls or ceilings finished in drywall that are in poor condition? ❑ **No** ❑ **Yes** Is, so where: ______________________	• When the frame of a house is not seismically braced, drywall is readily damaged by an earthquake and can be a hazard to occupants.
D6.3	❑ **Masonry Veneers:** • Are masonry veneers used in the interior, such as for fireplace facing and decorative walls? ❑ **No** ❑ **Yes** If so, where: ______________________	• Because of the weight of masonry, failure of a veneer can cause severe damage or injury or make egress difficult.

D7	**WINDOWS AND GLASS**	
	• Where are the ❑ Picture windows ______________ ❑ Sliding glass doors ______________ ❑ Bay windows ______________ ❑ Glass walls ______________ ❑ Glass block walls ______________	• The large glass areas introduce weaker points in the structural frame of the house. The stresses concentrated at the corners of the window opening frequently cause the glass to shatter.
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	
	❑ **Other Considerations:**	

Risk	Recommendations	GUIDE References
	• Confirm that plaster is in good condition. Conditions to check for are long cracks and also areas softened by water leakage. • Repair or replace damaged plaster, especially if located at the ceilings.	p. 166
	• Inspect wall structure to determine the extent of lateral bracing present. If possible, upgrade bracing to minimize damage to finishes due to seismic forces.	p. 166
	• For requirements for anchoring of masonry veneer, consult Section B, Evaluating the Exterior.	p. 166 p. 68
	• Windows constitute a hazard from collapse due to large openings in the building structure (soft storey). For a more complete discussion of openings in the exterior, refer to Section B, Evaluating the Exterior.	p. 78
	• Change windows to safety glass, or install safety film to reduce dangers from flying glass. • Install a designed bracing system around the window frame structure to redirect the quake forces around the opening and reduce the likelihood of glass breakage.	p. 168

APPENDIX I

EARTHQUAKE UPGRADE MASTER PLAN

These worksheets were developed for use in preparing an upgrade plan for a specific house.

Earthquake Upgrade Master Plan

PROPERTY

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
OFF-SITE HAZARDS							
From geology:							
From topography:							
From infrastructure:							
From landscape:							
From neighbours' structures:							
From retention structures:							
Other:							

Earthquake Upgrade Master Plan

PROPERTY

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
ON-SITE HAZARDS							
From soil conditions:							
From on-site topography:							
From on-site infrastructure:							
From on-site landscape:							
From accessory structures:							
Other:							

Earthquake Upgrade Master Plan

EXTERIOR

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
EXTERIOR GENERAL							
Age related:							
General condition:							
Chimneys:							
Cracks:							
Shape complexity:							

Earthquake Upgrade Master Plan

EXTERIOR

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
"Soft" storeys:							
Overhangs:							
Setbacks:							
Roof structure:							
Other:							

Earthquake Upgrade Master Plan

EXTERIOR

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
EXTERIOR MATERIALS							
Cladding:							
Porches, sundecks and verandahs:							
Other:							
OPENINGS							
In corner:							
On each floor:							
Other:							
DRAINING WATER							
Other:							

Earthquake Upgrade Master Plan

INTERIOR

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
INTERIOR							
Foundations:							
House framing system:							
Cripple walls:							
Supporting walls:							

Earthquake Upgrade Master Plan

INTERIOR

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
Columns:							
Corners:							
Floor and roof diaphragms:							
Structural connections:							
Other:							

Earthquake Upgrade Master Plan — CONTENTS

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
CONTENTS							
Furniture:							
Books:							
Dishes and glassware:							
Displayed items:							
Electrical fixtures:							

Earthquake Upgrade Master Plan

CONTENTS

Description	Remarks	Risk			Units	Quantities	Estimated $
		1	2	3			
Water Tank:							
Furnace:							
Other:							

APPENDIX J

CREDITS

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Figure 1-1	Photo courtesy of the North & West Vancouver Emergency Program.
Figure 1-2	Map from the Geological Survey of Canada web site, www.seismo.nrcan.gc.ca.
Table 1-1	Table from Rainer et al, *Earthquake Damage in the San Francisco Area and Projection to Greater Vancouver*, p. 15.
Figure 1-3	Photo courtesy of the North & West Vancouver Emergency Program.
Figure 2-1	Drawing based on Figure J-1, *Supplement to the National Building Code of Canada 1995*, p. 205.
Figure 2-2	Based on Natural Resources Canada, "Canada Seismicity" from the *National Atlas of Canada*.
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Figure 2-4	Based on Natural Resources Canada, "Canada Seismicity" from the *National Atlas of Canada*.
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Figure 2-7	Drawing based on Yanev, Peter I., *Peace of Mind in Earthquake Country*, p. 67.
Figure 2-8	Photo courtesy of the North & West Vancouver Emergency Program.
Figure 3-1	Photo courtesy of the North & West Vancouver Emergency Program.
Figure 3-5	Photo by B.A. Palmquist.
Figure 4-1	Photo courtesy of George Sakkestad, Soquel, California.
Figure 4C-5	Helfant, David Benaroya, *Earthquake Safe: A Hazard Reduction Manual for Homes*, p. 31.
Figure 4C-11	Dietz, Albert G.H., *Dwelling House Construction*, p. 81.
Figure 4C-17	Dietz, pp. 78-79 and Anderson, L.O., *Guide to Improved Framed Walls for Houses*.
Figure 4C-22	Diagram courtesy of Simpson Strong Tie.
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Figure 4C-53	Diagram courtesy of Simpson Strong Tie.
Figure 4C-54	Diagram courtesy of Simpson Strong Tie.
Table C-1	Based on chart of common nails in Boaz, Joseph N., Ed., *Architectural Graphic Standards*, Sixth Edition, John Wiley & Sons, Toronto, 1970, p. 191.
Table C-2	Based on chart of common nails in Boaz, Joseph N., Ed., *Architectural Graphic Standards*, Sixth Edition, John Wiley & Sons, Toronto, 1970, p. 191.

Other useful information products from
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Canadian Wood-Frame House Construction 5031E
Building Solutions: A Problem Solving Guide for Builders and Renovators 2004E
Glossary of Housing Terms 1165E
Complying with Ventilation Requirements in the 1995 National Building Code 6451E
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